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Cainozoic stratigraphy of the Yeelirrie area, northeastern Yilgarn Block, Western Australia

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Abstract

Seven new formations are recognized in the Cainozoic continental cover of the Yeelirrie area, northeastern Yilgarn Block Western Australia. The oldest is the Westonia Formation, a mainly massive, light grey sandy claystone with local silicification and basal conglomerate. It unconformably overlies Precambrian basement and is overlain by the Mulline Formation, a mainly pisolitic, reddish brown to reddish yellow quartz or quartz and kaolin spherite sand with a supporting silt-clay matrix of iron and aluminium minerals. Next, the Menzies Formation, consists of variably altered red sandy clay and sandy claystone; within this formation there is the Bungarra Member, a red kaolin mudstone, the Volpress Member a sepiolitic kaolin mudstone, and the Yeelirrie Member, a red sandy claystone with secondary calcrete, sparry calcite and dolomite. The Mulline and Menzies Formations are unconformably overlain by the Gibson Formation, a mainly massive, red to yellow, quartz and kaolin spherite clayey sand and sand which forms much of the present land surface throughout major interfluves and valley sides and interfingers with the next three formations. The Wirraway Formation consists mainly of massive red quartz sand and clayey sand and occurs along major valley bottoms between and bordering playas. The Nuendah Formation consists of gravel, sand and clayey sand, channel/overbank, ridge-footslope and breakaway-front deposits. The Darlot Formation consists mainly of massive to stratified pan/playa gypsum and kaolin muds, and contains the Miranda Member, a massive to stratified gypsum deposit. This lithostratigraphic framework provides a basis for future work into the nature and origin of the Cainozoic cover in the Yeelirrie area and also throughout other parts of the Yilgarn Block.

Introduction

A continental cover mainly of Cainozoic age extends throughout much of southwestern Australia, covering more than 70% of the Precambrian bedrock (Jutson 1914, 1934; Stace *et al.* 1968; Playford *et al.* 1975). The cover ranges up to 80 m in thickness but is usually less than 30 m (Australian Groundwater Consultants 1972, Geological Survey of Western Australia 1975).

Many aspects of this cover have been documented in terms of geology, stratigraphy, petrology, physiography, palaeogeography, geomorphic processes, geomorphic history, pedology, weathering and groundwater (Jutson 1914, 1934; Mabbutt *et al.* 1963; Beard 1973, 1982; Butt *et al.* 1977; Churchward 1977; Mann & Deutscher 1978; Lively *et al.* 1979; Mann & Horwitz 1979; van de Graaff *et al.* 1979; Butt 1983, 1985; Bettenay 1984). However, no formal lithostratigraphic framework has been developed for these materials, and their nature (geometry, structure, texture, composition) and origin are still imperfectly known.

This paper divides the Cainozoic cover in the Yeelirrie area (Fig. 1) into seven new formations and four new members. The units are introduced to provide a framework and basis for later studies into the stratigraphy, geomorphology, lithology, granulometry, mineralogy, geochemistry, petrogenesis and developmental history of the cover in the Yeelirrie area and throughout other parts of the Yilgarn Block (Fig. 1B). A formal lithostratigraphic approach is taken because it provides the most objective basis from which origins may be inferred. This approach follows that adopted elsewhere wherein formal rock unit status has been given to similar clay and claystone (Lowry *et al.* 1972, Barnett 1980), laterite (Lindner & Drew in McWhae *et al.* 1958, de la Hunty 1965, Barnett 1980), sandy clay (Callen and Tedford 1976), calcrete (Maitland 1904, Glauert 1911, Semeniuk 1983) and siliciclastic sand (Logan *et al.* 1970, Playford & Low 1972, Semeniuk 1980, 1983).

Methods

Stratigraphic sections were examined and sampled from limited natural outcrop, drill core, auger holes, costeans and pits at more than 100 sites.

Type, reference and supplementary stratigraphic sections were sampled vertically by collecting samples from a representative portion of all lithic and diagenetically distinct units. Sketches were made and photographs were taken to record structures and facies associations.

To extract the sand fraction from indurated specimens selected samples were weighed, broken into chips and boiled in NaOH and/or HCl. Saprolite and sandy claystone chips were repeatedly boiled in NaOH. Lateritic duricrust chips were boiled in HCl and bauxitic duricrust chips were boiled repeatedly in NaOH and then HCl.

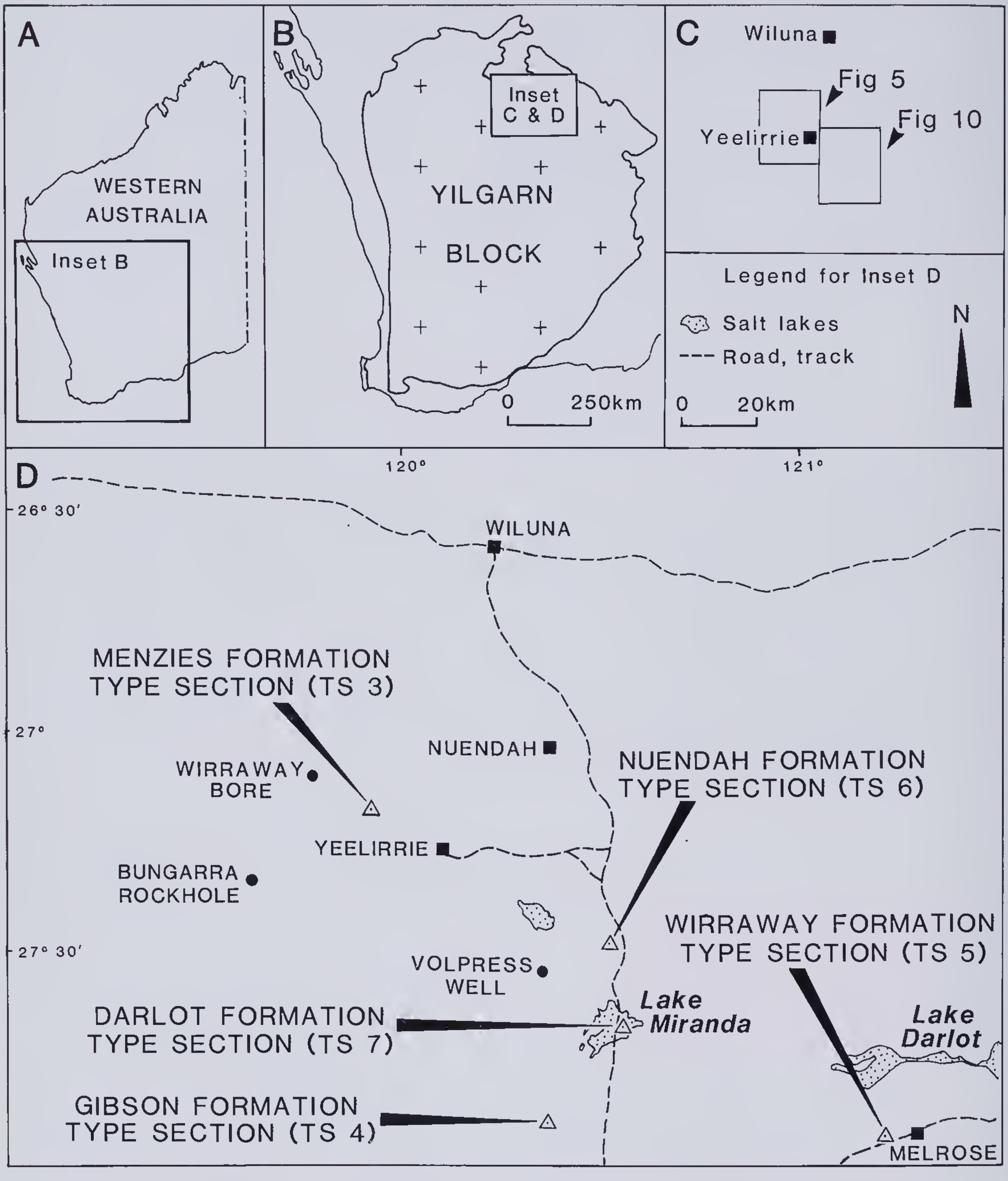

Figure 1.—Regional setting of Yeelirrie area. A and B. Location in Yilgarn Block, Western Australia. C. Yeelirrie area with location of Figs. 5 and 10. D. Yeelirrie area showing location of type sections.

Residues were washed through a 0.045 mm screen, dried, weighed and sieved. Loose sands were air dried, weighed and also sieved at half phi intervals. Terminology and procedures on sieving and grain size statistics are after Folk (1974). Selected samples were processed in the following manner: (1) impregnated with resin and thin sectioned; (2) examined with petrographic, electron and scanning electron microscopes; (3) examined with a microprobe; and (4) X-rayed using CoK-alpha radiation. X-ray diffractograms were interpreted according to JCPDS (1974) and Brindley & Brown (1980). The data are presented, along with inferred origins, in Glassford (1980).

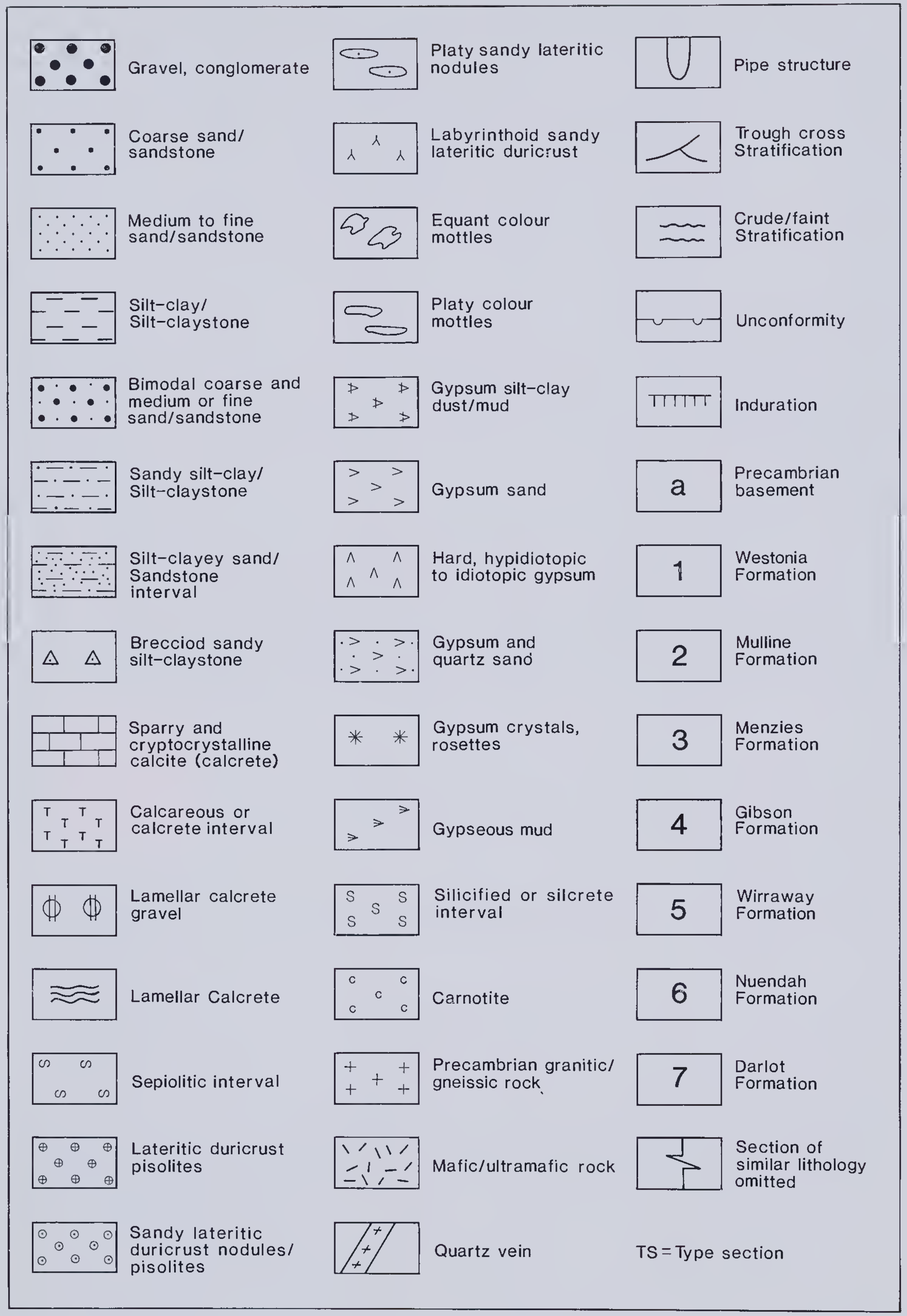

Figure 2.—Legend for stratigraphic sections.

Stratigraphic procedures and nomenclature are after Hedberg (1976) and Staines (1985). The legend for stratigraphic sections is presented in Fig. 2.

General setting

The Cainozoic cover of the Yeelirrie area is influenced by climate, topography and basement geology. These factors are described below.

The Yeelirrie area has a sub-tropical arid climate with 150-200 mm median annual precipitation and 4 000 mm mean annual evaporation (Gentilli 1971, Bureau of Meteorology 1975a,b).

Topographically the Yeelirrie area is between 650 to 450 m above mean sea level in the upper reaches of a south-east sloping major valley which begins at the continental divide (after Surveys and Mapping 1980). The major valley contains a chain of "salt lakes", which include Lake Miranda and Lake Darlot and is referred to here as the Yeelirrie valley.

Basement is interpreted to be predominantly Precambrian granitic rock (Williams 1975, Bunting & Williams 1979, Tingey 1985). The granitic rock weathers to saprolite which consists mainly of secondary aluminium minerals (kaolin, halloysite, gibbsite; c. 68%) and iron minerals (haematite, goethite; c. 2%) and residual quartz (c. 30%), (Grubb 1966, 1972; Gilkes *et al.* 1973; Sadlier & Gilkes 1976; Davy 1979; Anand & Gilkes 1984 a,b,c,d; Anand *et al.* 1985). Thus the saprolite of granitic rock has a matrix support fabric with about 30% quartz sand supported in a mainly kaolin clay matrix.

Stratigraphy

The lithostratigraphic units recognized in the cover of the Yeelirrie area are (time ranges from 1:250 000 geological map legends of Bunting & Williams 1979 and Tingey 1985):

7. Darlot Formation 7.1 Miranda Member 6. Nuendah Formation 5. Wirraway Formation	late Quaternary
4. Gibson Formation	late Tertiary to late Quaternary
3. Menzies Formation 3.3 Yeelirrie Member 3.2 Volpress Member 3.1 Bungarra Member	late Tertiary to early Quaternary
2. Mulline Formation 1. Westonia Formation	pre-Tertiary to late Tertiary

The major lithostratigraphic attributes of all units are summarized in Table 1 and general descriptions of type section lithology are presented in Tables 2 to 6, 8 and 9.

The Westonia and Mulline Formations are poorly represented in the Yeelirrie area, consequently their type sections are located outside the study area and units in the study area have been assigned to them by sequential lithostratigraphic correlation (Fig. 3).

Table 1

Summary of major characteristics of stratigraphic units which form the Cainozoic continental cover of the Yeelirrie area, northeastern Yilgarn Block, Western Australia.

Unit	Lithology	Geometry and dimensions	Structure	Stratigraphic relationships	Comments
Westonia Formation	Light grey sandy claystone to claystone minor clayey sandstone and conglomeratic sandstone.	Tabular to lenticular to channel-fill shaped and up to 5 m thick.	Massive to locally crudely bedded.	Unconformably overlies saprolite and Precambrian basement; typically overlain by the Mulline Formation.	Outcrop is very poor and typically confined to breakaways. The Westonia Formation differs from saprolite by being: generally greyer; locally stratified, locally conglomeratic in thin layers; moderately rich in kaolin spherites which are typically free of iron minerals. Saprolite differs from the Westonia Formation by: being generally whiter; occurrence of quartz veins; occurrence of discordant boundaries due to basic dykes; not containing kaolin spherites.
Mulline Formation	Reddish brown to yellowish brown lateritic/bauxitic duricrust of quartz and/or kaolin spherite sand supported in a silt-clay matrix of iron and aluminium minerals (mainly goethite, haematite, kaolin, gibbsite).	Sheet and blanket to lense form & less than 1 m to over 1 m thick.	Pisolitic to nodular to labyrinthoid (root/burrow structured).	Overlies unweathered granitic rock, saprolite, Westonia Formation and Menzies Formation; overlain by Gibson Formation.	Outcrop is poor and typically confined to breakaways. Pisolites and nodules of quartz and quartz and kaolin spherite sand with a matrix of iron (goethite, haematite) and aluminium (kaolin gibbsite) minerals are diagnostic. Includes primary and secondary (reworked) lateritic/bauxitic duricrusts. Becomes red and more haematitic when affected by bush fires.

Unit	Lithology	Geometry and dimensions	Structure	Stratigraphic relationships	Comments
Menzies Formation	Mainly red sandy clay and sandy claystone with some other facies (see members below). Framework sand consists of quartz and kaolin spherites rich in iron minerals. Matrix silt-clay consists mainly of goethite, haematite and kaolin.	Basin to broad major valley shaped fill. Typically up to 20 m thick.	Massive to weakly stratified	Unconformably overlies Precambrian basement; typically overlain by Gibson Formation	Outcrop is poor and typically confined to the bottom of major valleys. Red colour plus framework sand supported by a silt-clay matrix are diagnostic features.
Bungarra Member of Menzies Formation	Red Kaolin mudstone with minor quartz and carnotite.	Tabular to lense shaped up to 1 m thick. Locally may have a thin lense of sand at upper boundary.	Massive with scattered vesicles.	Overlies red sandy claystone facies and is overlain by Volpress Member.	Differs from the mud facies of the Darlot Formation by: having vesicles; being hard and brittle and breaking with a subconchoidal fracture; lacks gypsum; and is buried in contrast to Darlot Formation mud facies which may be buried or form modern playa mud flats.
Volpress Member of Menzies Formation	Black, grey and white sepiolitic kaolin mudstone with minor carnotite.	Tabular, lense to pod shaped and from less than 1 m to over 2 m thick.	Massive to veined with anastomose sepiolite.	Overlies Bungarra Member and is overlain by the Yeelirrie Member.	May be confused with calcrete but differs from the Yeelirrie Member by: not containing calcite; contains sepiolite; has a "mudstone" fabric and does not contain red sandy claystone.
Yeelirrie Member of Menzies Formation	White to pale brown to white with red. Red sandy clay and sandy claystone variably cemented, brecciated and replaced by calcrete (cryptocrystalline calcite) and sparry calcite.	Mound to pod to lense shaped and up to 5 m thick.	Domal to arcuate structured pods of calcrete grading to dispersed nodules, and rhizoconcretions of calcite.	Overlies Volpress Member locally and intergrades vertically and laterally with red sandy clay and sandy claystone facies. Locally overlain by Gibson Formation.	Outcrop is poor and typically confined to the bottom of major valleys. Calcretization of sandy clay and claystone are distinctive features.
Gibson Formation	Red to reddish yellow to yellow and sometimes locally white framework support siliciclastic clayey sand to sand, Framework grains mainly include quartz and kaolin spherites which typically contain iron minerals (goethite, haematite).	Sheet, interdune sheets up to 4 m thick and linear hills or ridges typically up to 10 m thick Overall up to 14 m thick.	Massive (ant, termite and root bioturbated) to rarely cross stratified.	Overlies the Mulline Formation and Menzies Formation; may interfinger or be overlain by the Nuendah, Wirraway and Darlot Formations.	The upper boundary forms much of the present day landsurface. Distinctive features include: massive structure; silt-clayey coarse and fine sand; minor to co-dominant amounts of nearly perfectly rounded and optimally developed kaolin spherites pigmented with irom minerals; reddish yellow to yellow colour resulting from goethite and haematite pigmenting kaolin coatings on grains; and numerous ant holes and termitariums.
Wirraway Formation	Red to reddish yellow quartz sand and clayey sand.	Sheets, linear hills, mounds or ridges and lunate hills or ridges up to more than 5 m thick.	Massive (ant, termite and root bioturbated) to locally cross-stratified.	Overlies the Menzies Formation and interfingers and overlies the Gibson, Nuendah and Darlot Formations.	Occurs along the axis of major valleys between around and on the margins of playas. In handspecimen the Wirraway Formation may be confused with the Gibson Formation. However the Wirraway Formation consists mainly of quartz with no kaolin spherites or minor amounts of very iron-rich kaolin spherites and fragments of kaolin spherites.
Nuendah Formation	Pale brown lithic gravels, quartz sands and clayey quartz sands.	Ridge-foot-slope channel and fan shaped and breakaway-front ribbons from less than 1 m to more than a few metres in thickness.	Massive to bedded to laminated. Bedding may be graded.	Overlies and interfingers with the Gibson and Wirraway Formations; overlies Precambrian basement and the Menzies Formation.	Has modern and pre-modern facies. Occurs along Precambrian basement ridge-footslopes, along breakaway-fronts and along dendritic tributary drainage tracts of major valley sides.

Unit	Lithology	Geometry and dimensions	Structure	Stratigraphic relationships	Comments
Darlot Formation	Red to brown to yellow to grey gypseous kaolin mud, with some other facies (see Miranda Member).	Varies widely in shape and thickness from tabular to lenticular sheets to filling circular and elongate basins. Ranges from less than 1 m to many metres thick.	Massive to laminated to bedded.	Overlies and interfingers with the Gibson and Wirraway Formations; overlies Precambrian basement.	Occurs intermittently along the axis of the Yeelirrie valley. It has modern and pre-modern facies equivalent to "salt lake" and associated deposits.
Miranda Member of Darlot Formation	White to brown gypsum sand and sandstone crystalline gypsum and gypsum silt-clay.	Sheets and hills from less than 1 m to over 5 m thick.	Massive to laminated to bedded.	Commonly overlies the mud facies of the Darlot Formation.	Distinctive handspecimen features include white to whitish brown and dominant gypsum composition.

Westonia Formation

Westonia Formation is the name proposed for a unit of light grey sandy claystone plus minor conglomeratic and other facies. The formation overlies unweathered and weathered (saprolite) Precambrian basement and is overlain by the Mulline Formation. (Tables 1, 2).

Derivation of name. Named after Westonia, a gold mining town several hundred metres south of the type section, lat. 31° 18′S, long. 118° 41′E, Southern Cross 1:250 000 sheet.

Type section. The designated type section is an escarpment produced by the collapse of a portion of the roof of the old Edna May gold mine, lat. 31° 18′S, long. 118° 41′E, Southern Cross 1:250 000 sheet (Table 2: Figs 3, Tr. 6 and 4,TS1).

A new phase of underground gold mining in the vicinity of the type section may progress to open cut mining and thereby endanger the designated type section. Therefore

Table 2

General description of lithology.
Westonia Formation type section.

Depth (m)	Description	Rock unit
0-0.5	Sandy laterite; reddish brown	Mulline Formation
0.5-0.75	Sandy claystone; light grey, massive, matrix supported, with unimodal, medium to fine, quartz and kaolin spherite sand, reddish brown soft platy mottles.	
0.75-1.0	Sandy claystone: as above but unconsolidated and without colour mottles.	
1.0-2.0	Sandy claystone light grey, massive and trough stratified, matrix supported, with unimodal, medium to fine quartz and kaolin spherite sand; hard, flint clay fracture.	Westonia Formation
2.0-4.0	Sandy claystone; light grey massive and pipe-structured, matrix supported with unimodal, medium to fine, quartz and kaolin spherite sand; hard reddish brown nodular and irregular mottles.	
4.0-4.2	Pebbly sandy claystone; light grey, massive, with quartz pebbles supported in a matrix of quartz and kaolin spherite sand and kaolin flint clay.	
4.2-5.0+	Gneissic saprolite	Archaean Basement

two reference sections are also designated. The first is in the face of a breakaway, lat. 30° 7′S, long. 120° 14′E, Kalgoorlie 1:250 000 sheet (Tr. 4-1 of Fig. 3). This section is remote with access by a track which is very poorly defined and difficult to negotiate. Therefore a second readily accessible but incomplete and thinner section is also designated. This section is a low breakaway on the north side of the Perth to Kalgoorlie main road, lat. 31° 16′S, long. 120° 1′E, Boorabbin 1:250 000 sheet (Tr. 5-1 of Fig. 3).

Distribution. The Westonia Formation does not crop out extensively and is poorly represented in the Yeelirrie area. Outcrop is typically confined to interfluve breakaways and outside the study area to valley bottom breakaways which in places border playas (Figs 3,5).

Surface features. Where the upper surface of the Westonia Formation crops out the exposure is typically limited to a few square metres and is characterized by an irregular surface of erosion.

Geometry and dimensions. Although there are only a few clear exposures, extrapolation of discontinuous exposures indicate that the formation is thin and generally tabular, lobate to lenticular to channel-like-fill shaped, with maximum thickness up to 5 m (Fig. 3).

Lithic characteristics. The Westonia Formation is massive to crudely trough bedded. It is usually pale grey with scattered red to orange mottles. The formation has vertical pipes filled with sandy claystone similar to the host sandy claystone within which the pipes occur. Pipe structures are usually outlined by red margins, are more mottled, and may contain scattered sesquioxide gravels.

The formation has the following facies (Figs 3,4):

1. Sandy claystone and claystone facies. Sandy claystone is massive and at handspecimen scale has a matrix support fabric. At a microscopic scale it has a grain support fabric with framework grains of quartz and kaolin spherite sand (Killigrew & Glassford 1976) and a matrix of disordered kaolin clay. Claystone is also massive and at a handspecimen scale has a "mudstone" fabric (fabric term after Dunham 1962), and at the microscopic scale it also typically has a grain support fabric with a framework of kaolin spherite sand. Both facies may locally be partly silicified (Figs 3; 4, TS1).

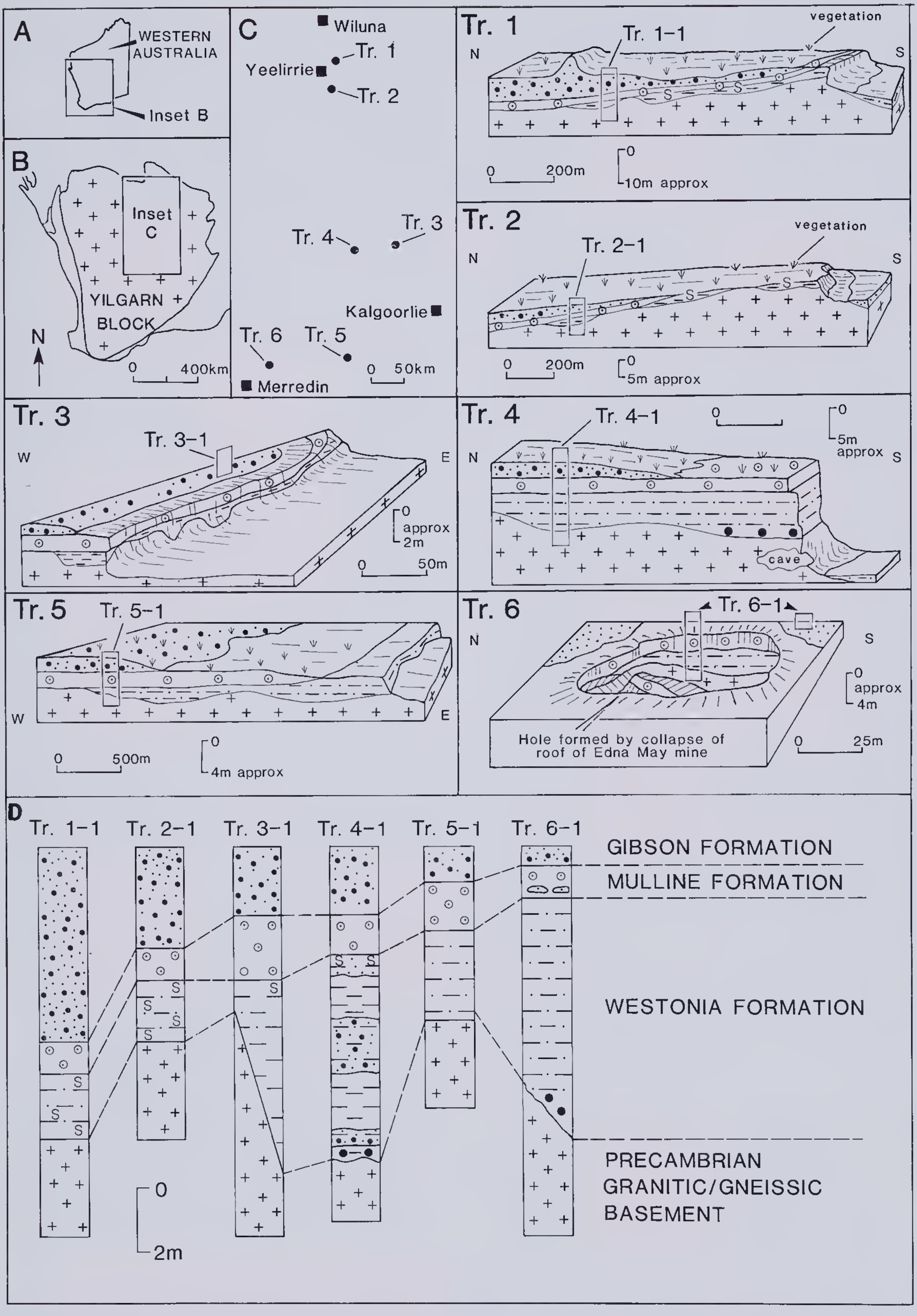

Figure 3.—Regional to medium scale settings for Westonia Formation and Mulline Formation type sections. A,B,C. Location of stratigraphic transects (Tr.) in the Yilgarn Block, Western Australia. Tr.1 to Tr.6, transects showing large to medium scale geomorphic and stratigraphic settings for stratigraphic sections. D. Generalized stratigraphic sections showing that the Westonia (Tr.6-1) and Mulline (Tr.3-1) Formations can be correlated from their respective type sections (Tr.6-1 and Tr.3-1) to the Yeelirrie area (Tr.1-1and Tr.2-1).

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2. Sandstone to muddy sandstone facies. This facies is massive to locally bedded and has a grain support fabric with a quartz sand framework and a disordered kaolin clay or flint-clay matrix. In the Yeelirrie area this facies is nearly wholly silicified (Butt 1983, 1985).
3. Conglomeratic facies. This facies varies from clayey conglomerate through sandy and clayey conglomerate to conglomeratic sandstone (Figs 3; 4, TS1). It is commonly a basal unit and massive to crudely layered. Gravels are typically rounded, pebble sized (4 to 64 mm in diameter) quartz. Matrix material is composed of kaolin spherite sand and/or disordered kaolin clay. The (basal) conglomerate facies is sporadic in occurrence.

The kaolin clay component of all facies is typically hard, does not develop plasticity and commonly breaks with an uneven or sub-conchoidal fracture. These properties of the Westonia Formation are also shared by flint clay (Loughnan 1971, 1975, 1978).

Fossils. The Westonia Formation generally lacks fossils but in places it contains roughly ellipsoidal casts 2 to 5 cm long and 1 to 2 cm in diameter which have been attributed by Kriewaldt (1969, p. 50-54) to the pupae of *Leptopius* sp. (Jackson 1941, p. 72-74). However they are more likely to be the brood cell of solitary native bees, superfamily Apoidea (T. S. Houston, W.A. Museum, pers. comm. 1986). Some brood cells are connected to a krotovina. The sandy claystone of the formation is generally light grey but in the vicinity of brood cells it is red to orange for 1 to 20 mm. The brood cells are usually part to completely filled with relatively more porous quartz and kaolin spherite sand and this fill is typically red or orange. Pipes within the formation may be tap-root casts.

Stratigraphic relationships. At the type section the Westonia Formation unconformably overlies gneissic saprolite and is itself overlain by the Mulline Formation. The lower boundary of the Westonia Formation is sharp, flat to gently dipping, and near planar, and locally varies to irregular and steeply dipping in the form of V and U-shaped valleys (Fig. 3, Tr. 3). These valleys have amplitudes of a few metres over distances of a few metres. The lower boundary is typically concealed and in places characterised by a thin basal conglomerate. The upper boundary is commonly sharp to abruptly gradational with overlying Mulline Formation, and it is generally flat to gently dipping, and near-planar to broadly undulose.

The Westonia Formation may be laterally equivalent geographically, but not temporally equivalent, to *in situ* pallid zone (saprolite) for where contacts are discernible the Westonia Formation unconformably overlies saprolite.

Discussion. The Westonia Formation is easily confused with *in situ* weathered Precambrian basement rock. This applies especially to the sandy claystone facies of the formation because it is similar in handspecimen with granitic saprolite. However sandy claystone and claystone facies typically have kaolin spherites whereas deeply weathered granitic rock *does not contain kaolin spherites* (Killigrew & Glassford 1976). Furthermore, Westonia Formation can be distinguished from saprolite by generally being grey, the presence of stratification, conglomerate layers and sporadic well-rounded quartz pebbles. In addition, saprolite can be distinguished from the Westonia Formation by generally being white, the presence of quartz veins and their truncation at the unconformity between saprolite and Westonia Formation, and by palimpsest gneissic structures and granitic fabrics.

In the Yeelirrie area the Westonia Formation has been previously mapped as Falconer and Nuendah landform—regolith systems (modified from land systems of Mabbutt *et al.* 1963) by Churchward (1977) and as deeply weathered rock, silcrete-siliceous rock with angular quartz grains, and sandstone, siltstone, claystone and conglomerate by Bunting and Williams (1979). In the Kalgoorlie 1:250 000 sheet area it has been mapped and described as Old Alluvium (Kriewaldt 1969, p. 22-31). Throughout the Yilgarn Block it has been referred to as saprolite derived alluvial sediment (Killigrew & Glassford 1976).

Stratified and kaolin spherite-rich sandy claystone, designated here as Westonia Formation, has been incorrectly identified in the Merredin area (Brewer & Bettenay 1973) and in the Westonia area (Webster & Mann 1984) as the mottled and pallid zones of *in situ* weathered Precambrian basement granitic rock.

Mulline Formation

The Mulline Formation is the name proposed for a unit of reddish brown to yellowish brown sandy lateritic to bauxitic duricrust which overlies saprolite and Westonia Formation and typically is overlain by the Gibson Formation (Tables 1, 3).

Derivation of name. Named after the abandoned gold mining town of Mulline, lat. 29° 47'S, long. 120° 31'E, Menzies 1:250 000 map sheet.

Type section. The designated type section is the face of a breakaway, west of a small playa, lat. 29° 47'S, long. 120° 57'E, Menzies 1:250 000 map sheet (Table 3; Figs 3, Tr.3); 4, TS3).

Distribution. The Mulline Formation is poorly exposed and typically covered by sand of the Gibson Formation throughout much of the Yeelirrie area, including the continental divide (Figs 3, 4, 5). Outside the Yeelirrie area outcrop occurs as lateritic gravel plains (Stace *et al.* 1968) or at the top and in the face of breakaways. The formation occurs throughout the northern interfluve plateau and the southern valley side of the Yeelirrie valley.

Surface features. Where the Mulline Formation crops out it has a relict surface. The outcrop is often characterized at a small to fine scale by an irregular morphology and patchy veneers of hard, pisolitic to nodular sandy gravel.

Geometry and dimensions. The formation is typically sheet-like and usually less than 1 m thick over areas of a few tens of square metres to many tens of square kilometres outside the study area. Its geometry is inferred by correlating and extrapolating the discontinuous outcrops.

Lithic characteristics. The Mulline Formation consists of reddish to yellowish brown sandy lateritic to bauxitic duricrust materials. It locally exhitits crude bedding, but generally it lacks bedding and is typically characterized by a pisolitic, nodular, platy or labyrinthoid structure (Fig. 4).

Pisolites, nodules and plates consist of a nucleus (ranging from a few mm to many cm in diameter) and a thin (c. 0.125 to 5 mm) laminated envelope. The pisolite nucleus typically consists of a framework of quartz or quartz and kaolin spherite sand supported in a silt-clay

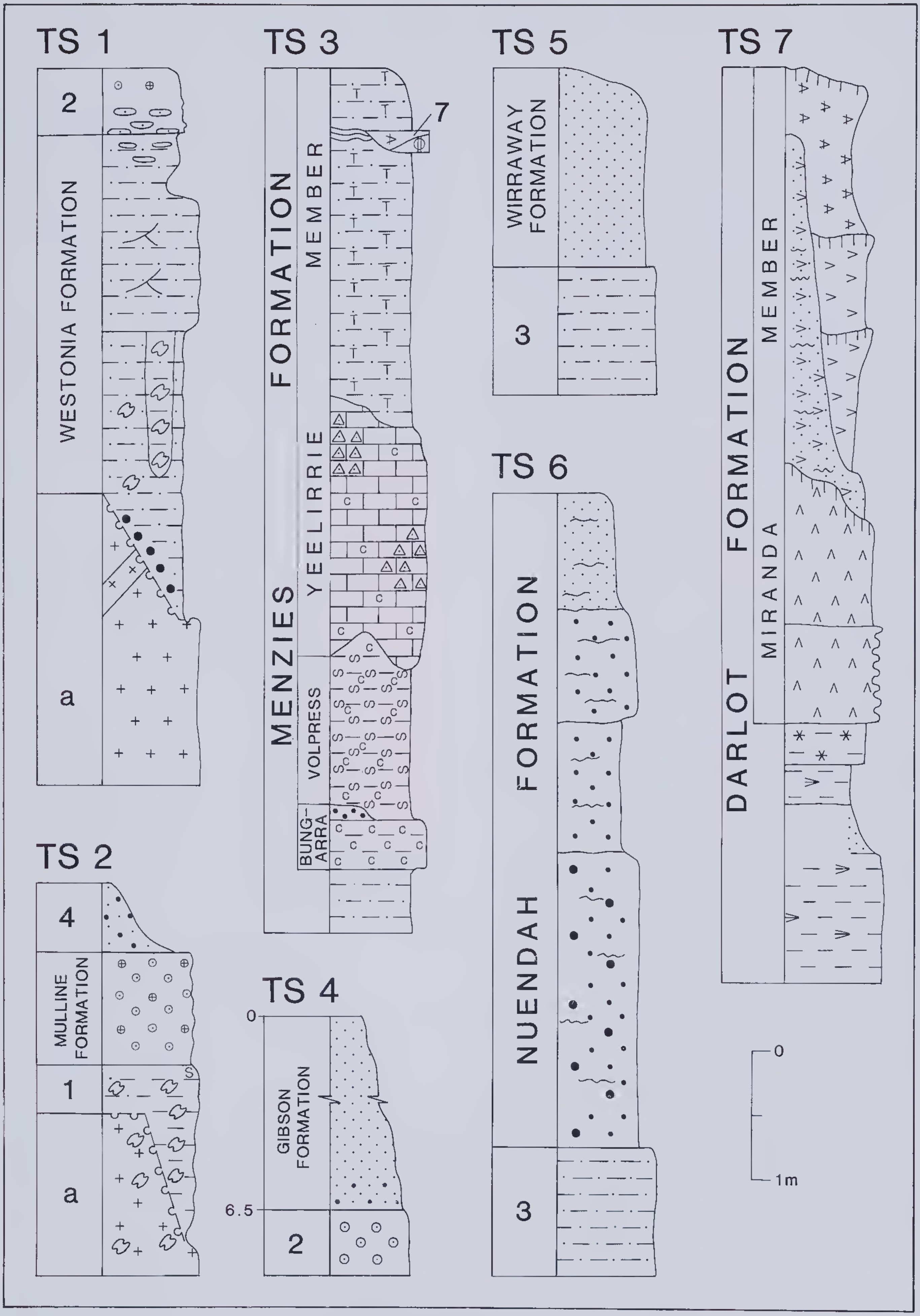

Figure 4.—Type section (TS) stratigraphic sections for the: Westonia Formation (TS1); Mulline Formation (TS2); Menzies Formation (TS3); Gibson Formation (TS4); Wirraway Formation (TS5); Nuendah Formation (TS6); and Darlot Formation (TS7). See Fig. 1 for location.

Table 3

General description of lithology, Mulline Formation type section.

Depth (m)	Description	Rock unit
0-0.5	Clayey sand; reddish yellow	Gibson Formation
0.5-1.75	Sandy laterite: yellowish brown, pisolitic; pisolites form a framework supported fabric: pisolites have a nucleus of fine skewed, moderately well to poorly sorted, fine to very fine quartz and kaolin spherite sand supported in a silt and clay matrix of geothite, haematite, kaolin and quartz; pisolites have a thin laminated envelope or pellicle of silt and clay sized goethite, haematite, kaolin and quartz.	Mulline Formation
1.75-3.1	Claystone; light grey, colour mottled.	Westonia Formation
3.1-3.5+	Gneissic saprolite	Archaean Basement

sized matrix of iron and aluminium minerals (typically goethite, haematite, kaolin and gibbsite) and quartz. Envelopes generally consist of similar silt-clay sized iron and aluminium minerals and quartz. The inter-pisolite/nodule/plate domain may consist of void space and/or sandy silt-clay or silt-clayey sands.

Labyrinthoid structure consists of a tortuous arrangement of vermiform to vesicular voids and labyrinthoid walls. The walls are similar to the nuclei of pisolites in that they consist of quartz and kaolin spherite sand with, or supported in, a silt-clay sized matrix of iron and aluminium minerals and quartz and the walls may exhibit envelope veneers.

Framework quartz and kaolin spherite sand of pisolites and nodules from the type section constitute 15 to 20% by weight of the rock and are fine skewed, moderately well to poorly sorted, fine to very fine sand. The mean size of the size fraction greater than 0.045 mm is 0.078 mm or very fine sand.

Mulline Formation kaolin spherites and matrix silt-clay are pigmented red and yellow by haematite and goethite. This contrasts with the kaolin spherites and most of the silt-clay of the Westonia Formation, which are essentially free of haematite and goethite.

Fossils. The formation in places contains trace fossils which are similar to those previously described in the Westonia Formation. The fossils have also been noted by Kriewaldt (1967, 1969, 1970) in the same unit, designated here as the Mulline Formation (Fig. 3) throughout much of the Menzies and Kalgoorlie 1:250 000 map areas.

Stratigraphic relationships. The Mulline Formation has an abrupt to gradational contact whith underlying Westonia Formation and an abruptly gradational contact with overlying Gibson Formation. Both upper and lower contacts are low angled and near-planar (Figs 3, 4).

Discussion. The Mulline Formation can be distinguished from other units mainly by its lateritic or bauxitic duricrust nature; this includes pisolitic, nodular, platy, and labyrinthoid structures; iron and aluminium minerals (e.g. goethite, haematite, kaolin, gibbsite); and silt-clay sized matrix which supports a framework of quartz or quartz and kaolin spherite sand.

The unit designated Mulline Formation has been mapped previously in the Yeelirrie area as Falconer and Nuendah landform-regolith systems by Churchward (1977), Tertiary laterite (massive and pisolitic limonite deposits and cemented ironstone gravel) by Bunting and Williams (1979), and described or mapped in the Yeelirrie and surrounding areas as, sandy laterite or duricrust, and as variously altered, wholly or partly desert aeolian sediment (Killigrew and Glassford 1976, Glassford & Killigrew 1979, and Glassford 1980).

Menzies Formation

The Menzies Formation is the name proposed for a unit of red sandy clay and sandy claystone which encloses lesser amounts of calcite-cemented sandy clay, sepiolite-cemented mudstone, mudstone, laminated calcite and clayey sand. The formation typically overlies granitic rock and is overlain by the Gibson Formation. (Tables 1, 4).

There are three distinct and spatially inter-related lithologies in the formation which are given member

Table 4

General description of lithology, Menzies Formation type section.

Depth (m)	Description	Rock unit
0-0.55	Sandy clay; light to medium reddish brown, massive, matrix supported, unimodal, fine skewed, moderately sorted, fine, quartz and kaolin spherite sand with a silt and clay matrix of calcite, quartz and kaolin; scattered off white calcrete pisolites and rhizoconcretions,	Yeelirrie Member of the Menzies Formation
0.55-0.65	Sandy gypsite; white.	Darlot Formation
0.65-0.75	Laminar calcrete breccia; off white to light brown, angular gravels of laminar calcrete.	
0.75-2.50	Sandy clay; light to medium reddish brown, massive, matrix supported unimodal, fine skewed, moderately sorted, fine quartz and kaolin spherite sand with a silt and clay matrix of calcite, quartz and kaolin; scattered calcite pisolites and rhizoconcretions.	Yeelirrie Member of the Menzies Formation
2.5-4.5	Calcrete; reddish brown and white; red sandy claystone breccia supported in cryptocrystalline calcite; red sandy claystone breccia domains have a matrix supported fabric; framework grains are unimodal, fine skewed, moderately sorted, quartz and kaolin spherite sand; matrix silt and clay is mainly kaolin, minor carnotite; calcrete domains are cryptocrystalline calcite with scattered quartz and kaolin sand; quartz grains in calcrete have ragged edges.	
4.5-5.6	Sepiolitic claystone; dark grey and white, kaolin mudstone with veins of sepiolite; minor carnotite.	Volpress Member of the Menzies Formation
5.6-5.7	Clayey sand; light reddish brown, unimodal, framework supported, moderately sorted, coarse, quartz sand; soft, unconsolidated.	Bungarra Member of the Menzies Formation
5.7-6.1	Mudstone; red, vesicular and massive kaolin mudstone; minor carnotite; brittle, subconchoidal fracture.	
6.1-7.0+	Sandy claystone; reddish brown, massive, matrix supported fabric; framework grains unimodal, fine skewed, moderately sorted, fine, quartz and kaolin spherite sand.	Menzies Formation

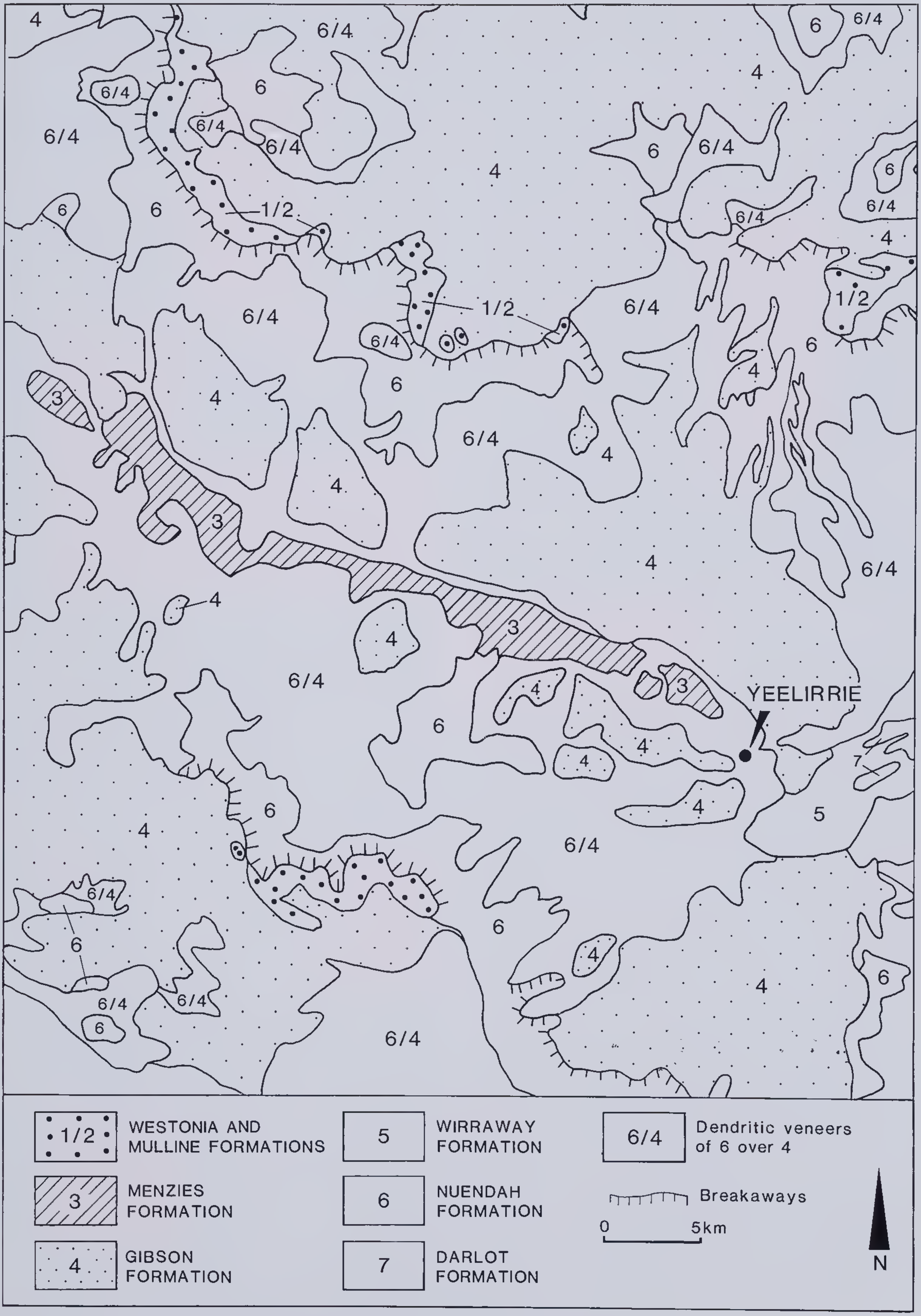

Figure 5.—Map showing distribution of formations in the upper central Yeelirrie valley. See Fig. 1 for locations.

status. The members are: Bungarra Member; Volpress Member: and Yeelirrie Member and they are described later.

Derivation of name. Named after Menzies townsite, lat. 29°41'S, long. 121°2'E, Menzies 1:250 000 sheet.

Type section. The designated type section is a uranium exploration trench, termed by Western Mining Corporation, number 2 slot or bottle-slot lat. 27°11'S, long. 119°55'E, Sandstone 1:250 000 sheet (Table 4; Figs 4.TS3;6A).

Distribution. The Menzies Formation has been encountered in costeans (Western Mining Corporation's slots 1 and 2), drill holes, trenches and creek incisions throughout valley side and valley floor landsurface positions of the Yeelirrie area. Outcrop is poor and generally occurs as small patches along the axis of the Yeelirrie valley and along the floors and sides of tributary incisions (Fig. 5).

Surface features. Red sandy clay and sandy claystone generally forms the upper part of the formation in valley-side gully locations of the Yeelirrie valley and it usually has a flat to gullied erosional surface. The calcite-cemented portion of the formation usually occurs along the axis of the Yeelirrie valley and has a broad hummocky erosional surface, locally with a veneer of gravelly calcrete and calcareous sandy silt-clay.

Geometry and dimensions. In the Yeelirrie area the Menzies Formation forms a very broad basin-shaped valley fill. The lower boundary is concealed and has only been noted at a depth of about 18 m (Fig. 7, Site 175). Seismic contour and drilling data suggest the lower boundary is a broad valley form with the thickness of the formation increasing down valley (Australian Groundwater Consultants 1972).

Lithic characteristics. The Menzies Formation consists mainly of red sandy clay to red sandy claystone and locally red clayey sand and sandstone which are *laterally and vertically interrelated* in that they are *interbedded and intergradational over a few metres.* These main lithologies are also interlayered with other diagenetic and allochthonous sediment types such as (Fig. 7): (1) calcitic sandy clay to calcite with minor dolomite-cemented red sandy claystone, (2) sepiolite-cemented kaolin mudstone, (3) red kaolin mudstone, (4) laminar calcite and (5) very coarse to coarse clayey sand (Fig. 4.TS3); these latter lithologic intercalations however are minor components within the red sandy clay and sandy claystone which form the bulk of the formation.

The red sandy clay and sandy claystone is massive to weakly stratified. Stratification is most apparent where occasional thin calcite laminae occur. The sediment is composed of quartz, kaolin spherites (pigmented with goethite and haematite) and rare feldspar and sesquioxide (lateritic) framework grains with a goethite and haematite pigmented kaolin silt-clay matrix. Monocrystalline quartz grains predominate, although locally, polycrystalline quartz grains occur in minor amounts. The quartz grains generally have a haematite and goethite pigmented coating of kaolin. The matrix often has a curvilinear laminated structure consistent with flow lines and meniscus lines. These features indicate that much of the matrix is a cement formed after the framework grains were deposited.

The fraction of the red sandy claystone and clayey sandstone greater than 0.045 mm is 20 to 80% sand by weight. The sand is bimodal to very poorly unimodal, strongly fine skewed to near-symmetrical, moderate to poorly sorted, medium to fine sand, in places ranging from coarse to very fine sand.

Fossils. Apart from possible algal filaments in the Bungarra Member the formation appears to be devoid of fossils.

Stratigraphic relationships. The Menzies Formation has a sharp contact with underlying granitic rock and is unconformably overlain, usually with a sharp contact, by the Gibson, Wirraway and Nuendah formations (Fig. 7). It tends to be laterally equivalent geographically to, but generally does not overlie the Mulline Formation. This is because the Mulline Formation is typically confined to upland plateaux and the Menzies Formation is best developed under major valley sides and bottoms. Where the Mulline Formation has undergone reworking it may overlie the Menzies Formation (Fig. 8, Section 138).

Bungarra Member of Menzies Formation. Named after Bungarra rockhole, lat. 27°21'S, long. 119°36'E, Sandstone 1:250 000 sheet.

The Bungarra Member is a massive red kaolin mudstone up to 1 m thick which in places has a thin lens of clayey coarse sand at upper levels (Fig. 7, section 156). It was encountered in two trenches excavated by Western Mining Corporation and in drill cores over a distance of more than 10 km, and at a depth of about 1 to 8 m. This distribution is probably not continuous. Distinguishing features include: tabular shape with approximately straight and parallel upper and lower boundaries; massive structure with scattered millimetre-sized vugs; brittle with a sub-conchoidal fracture; "mudstone" fabric; red colour and dominantly kaolin clay composition with minor to trace amounts of silt to fine sand sized quartz; moderate amounts of carnotite as vug linings; 0.02% organic carbon; and a sparse network of dark fibres which may be fossilised algal filaments.

The Bungarra Member has a sharp near-horizontal contact with underlying and overlying red sandy clay and sandy claystone portions of the Menzies Formation, and in places underlies sepiolitic mudstone of the Volpress Member.

Volpress Member of Menzies Formation. Named after Volpress Well, lat. 27°34'S, long. 120°21'E, Sir Samuel 1:250 000 sheet.

The Volpress member is a black to grey and white mottled and veined sepiolitic mudstone (Fig. 4.TS3). It is characterised by: tabular to lens to pod shape; "mudstone" fabric with trace amounts of silt to fine sand sized quartz; white to black mottled appearance; sepiolitic kaolin composition with white anastomosing veins and blebs of sepiolite; minor amounts of carnotite; traces of smectite; and 0.12 to 0.36% organic carbon.

There is a lower sharp straight contact with red mudstone of the Bungarra Member and a discordant contact with the overlying calcite-cemented red sandy clay and sandy claystone facies of the Yeelirrie Member. The upper contact is gradational and undulating.

Yeelirrie Member of the Menzies Formation. Named after Yeelirrie homestead, lat. 27°20'S, long. 120°14'E, Sir Samuel 1:250 000.

The Yeelirrie Member is up to 5 m thick and crops out intermittently as broad mounds and depressions along the bottom of the Yeelirrie valley for over 100 km (Fig. 5). It forms thick lenses to pods tens of metres in diameter. In places pods exhibit a crude domal or arcuate structure which is roughly parallel with their dome surface form and similar to the caliche pseudo-anticlines of Jennings & Sweeting (1961). This member consists of five lithofacies: (a) white and red calcitic sandy claystone breccia: (b) massive white calcite; (c) massive to cavernous, white and grey pods of calcite and dolomite; (d) laminar calcite sheets and breccioid clasts of laminar calcite; and (e) pisolitic to nodular to rhizoconcretionary calcite supported in sandy clay (Fig. 4,TS3).

The white and red calcitic sandy claystone breccia facies forms a transitional zone between red sandy claystone and massive calcite or calcrete. The massive to cavernous, white and grey pods of calcite and dolomite form a zone within the red calcitic sandy claystone breccia. The lamellar calcite sheets and breccioid clasts of lamellar calcite plus pisolitic to rhizoconcretionary calcite in sandy clay tend to overlie the other facies. Minor to trace amounts of carnotite occurs in association with the calcite and dolomite domains of all facies.

Following the digestion of carbonates in HCl, up to 15% by weight of greater than 0.045 mm quartz and kaolin spherite grains remain. This residue is typically poorly unimodal, fine skewed, moderately sorted, fine sand.

The Yeelirrie Member has a broad gradational lateral contact with red sandy claystone and an irregular discordant contact with the underlying Volpress Member. The Yeelirrie Member is unconformably overlain by the Gibson, Wirraway, Nuendah and Darlot Formations or, in places along the axis of the Yeelirrie valley, it forms the contemporary landsurface.

Discussion. The red sandy clay and sandy claystone facies of the Menzies Formation has a varied provenance. Monocrystalline quartz, polycrystalline quartz and feldspar indicate contributions from granitic rock, saprolite, metamorphic rock and the Westonia Formation. Kaolin spherites and laterite clasts indicate contributions from laterite of the Mulline Formation. Much of the matrix material of the red sandy clay and sandy claystone facies is a cement of kaolin, goethite and haematite which formed after the framework grains were deposited. This host red sandy clay and sandy claystone has been locally overprinted by calcite thereby forming the Yeelirrie Member.

The red sandy clay and sandy claystone facies of the Menzies Formation can be distinguished from the Westonia Formation by its redness, goethite and haematite pigmented kaolin spherites and matrix silt-clay. The matrix material breaks with an uneven fracture rather than a flint-clay sub-conchoidal fracture typical of the Westonia Formation. The red sandy clay and sandy claystone facies may also be superficially confused with the Wiluna Hardpan of Bettenay & Churchward (1974). However at its type section (lat. 24°3'S, long. 119°34'E, near Bulloo Downs in the Bangemall Basin, c. 370 km NNW of Yeelirrie) the Wiluna Hardpan is a conglomerate with pebbles of lateritic duricrust, quartzite, silcrete and shale supported in a red sandy clay matrix. Thus the Menzies Formation is not conglomeratic and can be distinguished from the Wiluna Hardpan which is conglomeratic. Furthermore the different lithic nature of the Wiluna Hardpan, as defined by Bettenay & Churchward (1974) *at its type section* reflects its location in the Bangemall Basin: in contrast the Menzies Formation type section is located in the Yilgarn Block and reflects that province.

The red sandy clay and sandy claystone facies in the Yeelirrie area has been referred to previously as hardpan (Teakle 1936, 1950; Mabbutt *et al.* 1963), Wiluna Hardpan (Bettenay & Churchward 1974), alluvium (Haycraft 1976), mainly altered desert aeolian valley fill (Glassford 1980) and as alluvial/fluvial/colluvial/aeolian channel fill (Arakel & McConchie 1982). The Yeelirrie Member has been referred to as: calcrete (Sofoulis 1963, Sanders 1974, Haycraft 1976, Arakel & McConchie 1982); valley or groundwater calcrete (Carlisle *et al.* 1978, Mann & Horwitz 1979); calcreted drainage lines (Churchward 1977); and calcite and dolomite brecciated, cemented and replaced, desert aeolian valley fill (Glassford 1980). The Volpress Member has been referred to as transition calcrete (Haycraft 1976), altered playa-lake sediment (Glassford 1980) and mottled calcrete (Arakel & McConchie 1982). The Bungarra Member has been referred to previously as altered playa and playa input fan sediment (Glassford 1980).

Gibson Formation

Gibson Formation is the name proposed for a unit which forms sand sheets and linear dunes. It is massive to locally weakly stratified red through reddish yellow to yellow and in places white clayey sand and sand. The formation typically overlies the Mulline and Menzies Formations (Tables 1,5).

Derivation of name. Named after the Gibson Desert the western margin of which includes the Yeelirrie area.

Type section. The designated type section is the face of a quarry in a linear dune on the south side of the Agnew to Sandstone road and 11 km west of the Agnew to Wiluna road, lat. 27°58'S, long. 120°24'E, Sir Samuel 1:250 000 sheet (Table 5; Figs 4, TS5;6B).

Distribution. The Gibson Formation is areally the most dominant land surface unit throughout the area. It occurs as a patchwork of large scale sand sheets on interfluve plateaux, valley side plains and on the continental divide between westerly and easterly sloping major valley systems (Figs 5: 6A,B;8).

Surface features. The surface of the Gibson Formation has four major expressions in the Yeelirrie area: relict spinifex covered sand flats; relict spinifex covered linear dunes: erosional *Acacia*-covered sand flats; and erosional and depositional dendritic to braided shallow channels.

Table 5

General description of lithology, Gibson Formation type section.

Depth (m)	Description	Rock unit
0-5.0	Sand; yellowish red to red, massive, framework supported; from top to bottom grades uniformly from unimodal to poorly unimodal and from fine to more fine skewed, and from well to moderately well sorted, and from fine to medium quartz and kaolin spherite sand.	
5.0-6.5	Sand, slightly clayey; red, massive to faintly stratified, framework supported, fine skewed, moderately sorted, medium sand; coarser sand consists of quartz, finer sand consists of quartz and kaolin spherites.	Gibson Formation
6.5-7.0	Sandy laterite; brownish red.	Mulline Formation

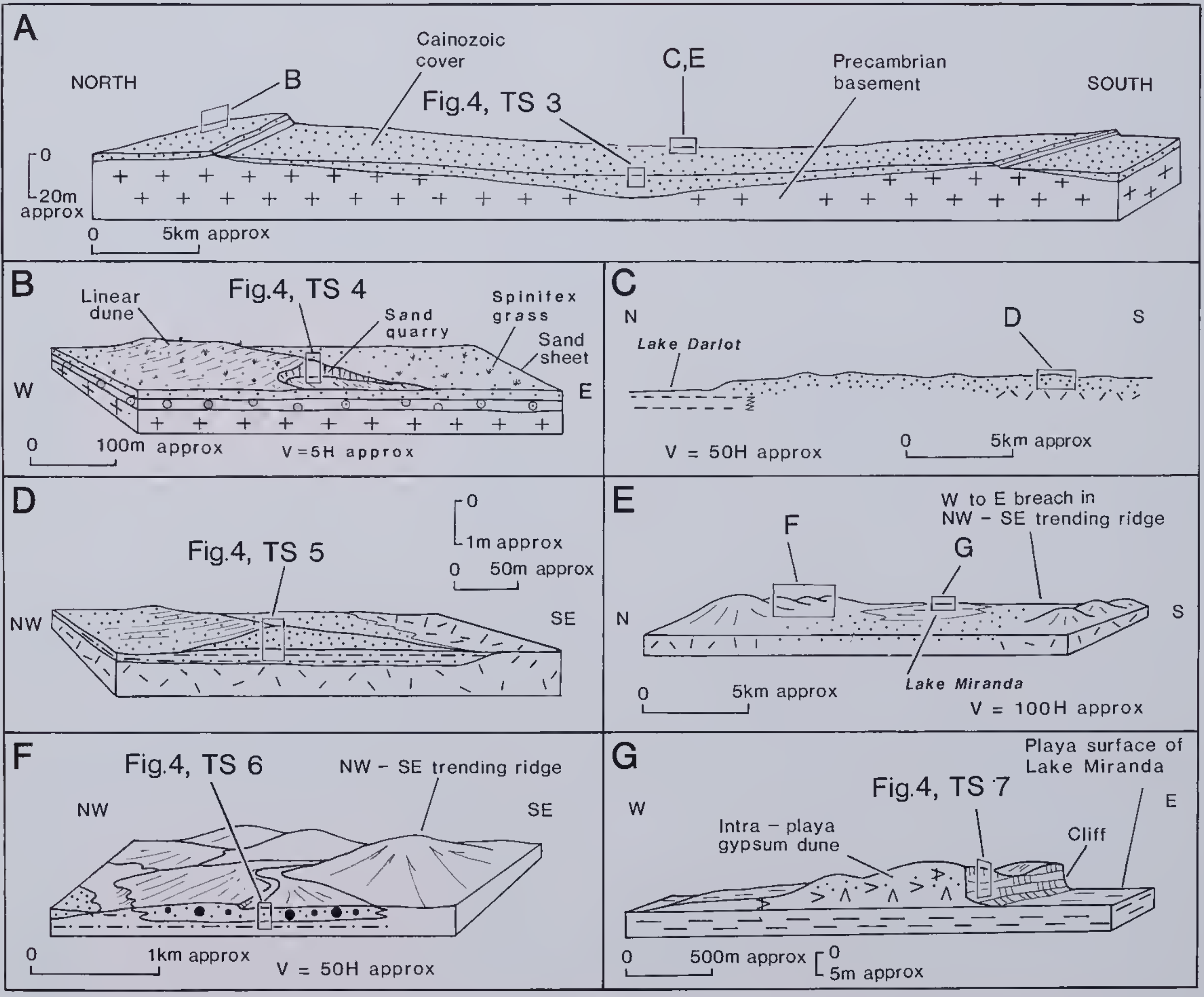

Figure 6.—Geomorphic and stratigraphic setting for the respective type and supplementary sections. A. Regional scale schematic section of the Yeelirrie valley showing location of smaller scale settings or sections. B, C, D, E, F, G. Medium scale geomorphic and stratigraphic settings for type sections of Fig. 4.

The surface of linear dunes is generally loose sand, however the surface of interdunes and spinifex covered sand sheets generally consists of a thin ($c. < 1$ cm) coherent crust overlain by a thin ($c. < 1$ cm) veneer of loose coarse sand. The coherent crust is formed by the packing of fines between larger grains, probably by rain-drop impact, and the binding action of *Chara sp.* filaments.

Geometry and dimensions. The Gibson Formation is a sand sheet which has been reworked into few to numerous linear dunes. The sand sheet in the Yeelirrie area is typically about 1 to 4 m thick and the linear sand dunes are generally about 5 to 10 m high (Figs 4;6b). Linear dunes are 0.5 to 3.5 km long, and 0.25 to 2 km apart. Dune orientation on average is 129° or NW to SE and ranges from 100° to 156°. Some dunes are symmetrical or asymmetrcal in cross-section, others exhibit complex cross-sectional asymmetry. That is crest to mid-flanks may be symmetrical and lower flanks on the same dune may be asymmetrical and vice versa. Thus the dunes are termed linear rather than the genetic terms longitudinal or transverse.

Lithic characteristics. Sands of the Gibson Formation range from red to yellowish red to reddish yellow to yellow and in places white. Sand sheets and linear sand dunes of the formation are usually massive, but relatively rare very faint cross-stratification occurs in some wind-exposed quarry faces. The formation has two primary facies, a sand sheet facies (which includes interdune sand sheet) and a linear sand dune facies.

Sand sheet facies typically consist of sand which is bimodal to poorly unimodal, fine skewed, moderately well to poorly sorted, coarse to fine sand with dust (silt-clay). The "coarse" mode ranges from very coarse to medium sand (2.0 to 0.25 mm) and the "fine" mode ranges from medium to very fine sand (0.25 to 0.125 mm). Sand sheet facies have approximately 2 to 20% fines (less than 0.09 mm fraction). The sand-dune facies contain sand which is bimodal to unimodal, fine skewed, moderate to well sorted and medium to fine. Sand dune facies have approximately 0.5 to 8% fines (less than 0.09 mm fraction).

All facies have two major framework grain types, quartz grains and kaolin spherites. Quartz grains have a characteristic coating of haematite and goethite-pigmented (disordered) kaolin in addition to silt-sized quartz. Quartz sand may range from about 60 to over 90% and kaolin spherites range from a few per cent to over 30%. Kaolin spherites are best developed and most abundant in fine sand-sized material (0.25 to 0.125 mm) of sand sheet, interdune sand sheet and linear dune facies. The spherites are unimodal, fine skewed, well to moderately sorted fine sand. They are extremely well rounded and pigmented red, reddish brown, reddish yellow or yellow by haematite and goethite. Kaolin spherites usually have a nucleus of pelletal to crudely oriented kaolin which is typically free of haematite and goethite and less commonly, quartz, opaque minerals or smaller spherites. The nucleus is encapsulated by a haematite and goethite pigmented oolitic kaolin envelope. Locally (e.g. some leeward dune flanks) sand to silt sized microcline may occur in minor amounts.

The silt-clay fraction of sand sheet and sand dune facies usually consists of quartz, disordered kaolin, haematite, goethite and minor feldspar and anatase.

Fossils. No fossils have been found in the formation.

Stratigraphic relationships. The Gibson Formation overlies the Mulline Formation and the Menzies Formation and in places is overlain by the Wirraway and Nuendah Formations. The lower boundary of the formation is sharp, flat to gently dipping and planar. The upper boundary is typically the present day land surface (Figs 3, 4, 6, 8).

Discussion. The occurrence, size, shape, roundness, internal structure, colour and composition of kaolin spherites in the Gibson Formation are consistent with it being mainly derived from the Menzies, Mulline and Westonia Formations.

The surface of the unit designated Gibson Formation has been mapped previously in the Yeelirrie area as: (1) Bullimore land system, sand plain or aeolian sand and described as red sand consisting of reworked and residual lateritic soils by Mabbutt *et al.* (1963); (2) Quaternary aeolian deposits described as unconsolidated sheets and dunes of sand by Australian Groundwater Consultants (1972); (3) Bullimore landform-regolith system (modified from Bullimore land system of Mabbutt *et al.* (1963); (4) depositional sand plains of aeolian and fluviatile deep sands, grits and clays by Churchward (1977); (5) Quaternary aeolian deposits (Qps), red and yellow quartz sand in dunes and sheets; and (6) Quaternary colluvium and alluvium (Qpz), dark red to brown clay to sandy loam by Bunting and Williams (1979); (7) spinifex sand plain with longitudinal dunes and acacia sand plain and described as relict desert aeolian sand sheet and dunes by Glassford (1980); and (8) aeolian sand plains with few or weak dunes by Beard (1984).

Wirraway Formation

The Wirraway Formation is the name proposed for a sheet to dune unit of massive to stratified, mainly red to reddish yellow quartz sand to quartz clayey sand. The formation typically overlies the Menzies and Gibson Formations and interfingers with the Nuendah and Darlot Formations (Tables 1,6).

Derivation of name. Named after Wirraway Bore, lat. 27° 5′S, long. 119°45′E, Sandstone 1:250 000 sheet.

Type section. The designated type section is a low, broad, linear dune south of Lake Darlot, lat. 27°56′S, long. 121° 13′ E, Sir Samuel 1:250 000 sheet Table 6; Figs 4, TS5; 6A,C,D).

Distribution. The Wirraway Formation occurs discontinuously along the axis of the Yeelirrie valley. It occurs near and between playas (extra-playa) as low broad linear channel-border dunes, around and on the edges of playas and pans (playa-border) as pan or playa-contiguous sheets and sinuous to lunate dunes, and within playas (intra-playa) as sheets and dunes (Figs 9,10).

Surface features. The surface is usually relict to erosional and vegetated. It also may be bare of vegitation as a reworked or primary depositional surface with sand ripples produced by the wind.

Geometry and dimensions. The Wirraway Formation occurs as thin sheets, low broad linear dunes and as sinuous to lunate dunes. It ranges from 1 to over 5 m thick (Figs 4; 6 A,C,D;9).

Lithic characteristics. The Wirraway Formation is a sheet to dune unit which consists typically of masive to locally stratified, red to reddish yellow to yellow quartz sand to quartz clayey sand. Outside the study area it has scattered rhizoconcretions at depth. On the basis of geometry and location relative to playas it may be divided into facies (Table 7). Channel-border dune facies tend to be red to reddish brown whereas other facies tend to be yellowish red to reddish yellow because of goethite and haematite pigmented kaolin clay coatings on quartz sand grains. The formation is typically massive but some lunate and modern dune facies are stratified. Overall, Wirraway Formation sand is positively skewed, moderately well to poorly sorted, locally very coarse but usually medium to fine quartz with 0.5 to 26% fines (Table 7). The crests of channel-border dunes are relatively coarser than the flanks. This is similar to some lunate dunes and contrasts with linear dunes of the Gibson Formation which have dune crests which are relatively finer than flanks.

Fossils. Apart from rhizoconcretions at depth in channel-border dunes located outside the Yeelirrie area, no fossils have been observed in the Wirraway Formation.

Stratigraphic relationships. The Wirraway Formation overlies the Menzies and Gibson Formations with a sharp, near-planar contact and locally interfingers with the Darlot Formation (Figs 4;6A,C,D;9).

Discussion. Apart from its different land surface position, geometry, grain size properties and stratigraphic relationships the Wirraway Formation can be distinguished from the Gibson Formation because the Gibson Formation typically has moderate amounts of

Table 6

General description of lithology.
Wirraway Formation type section.

Depth (m)	Description	Rock unit
0-1.5	Sand; red, masive, framework supported, unimodal, fine skewed, moderately to poorly sorted, medium quartz sand; fines (less than 0.09 mm) are 5.5% (top) to 6.8% (bottom).	Wirraway Formation
1.5-2.0+	Sandy claystone; reddish brown.	Menzies Formation

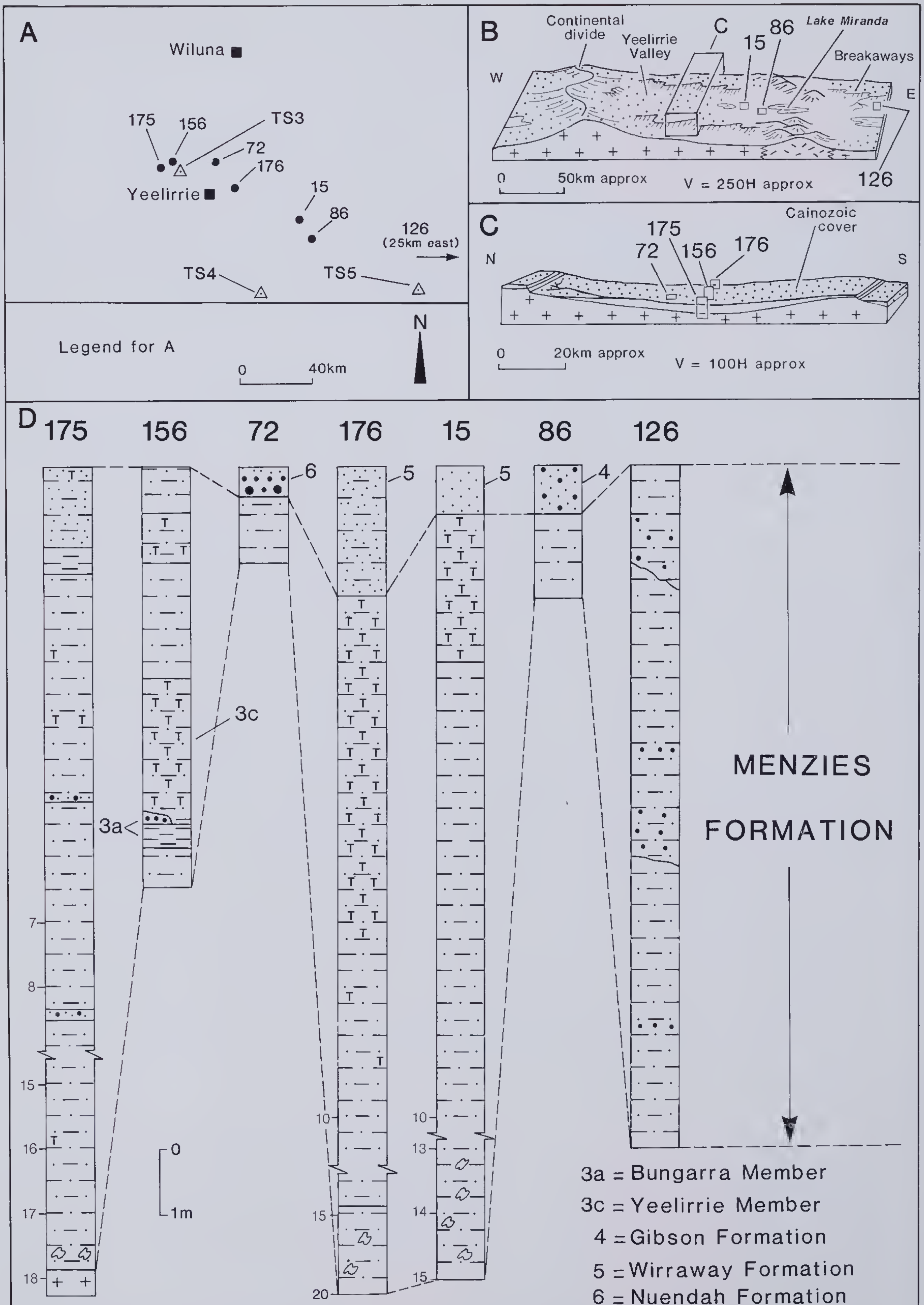

Figure 7.—Regional stratigraphy of the Menzies Formation in the Yeelirrie area. A,B. Location and geomorphic and stratigraphic settings of stratigraphic sections. D. Stratigraphic sections. Note: The Menzies Formation also occurs at the base of TS5 (see Fig. 4).

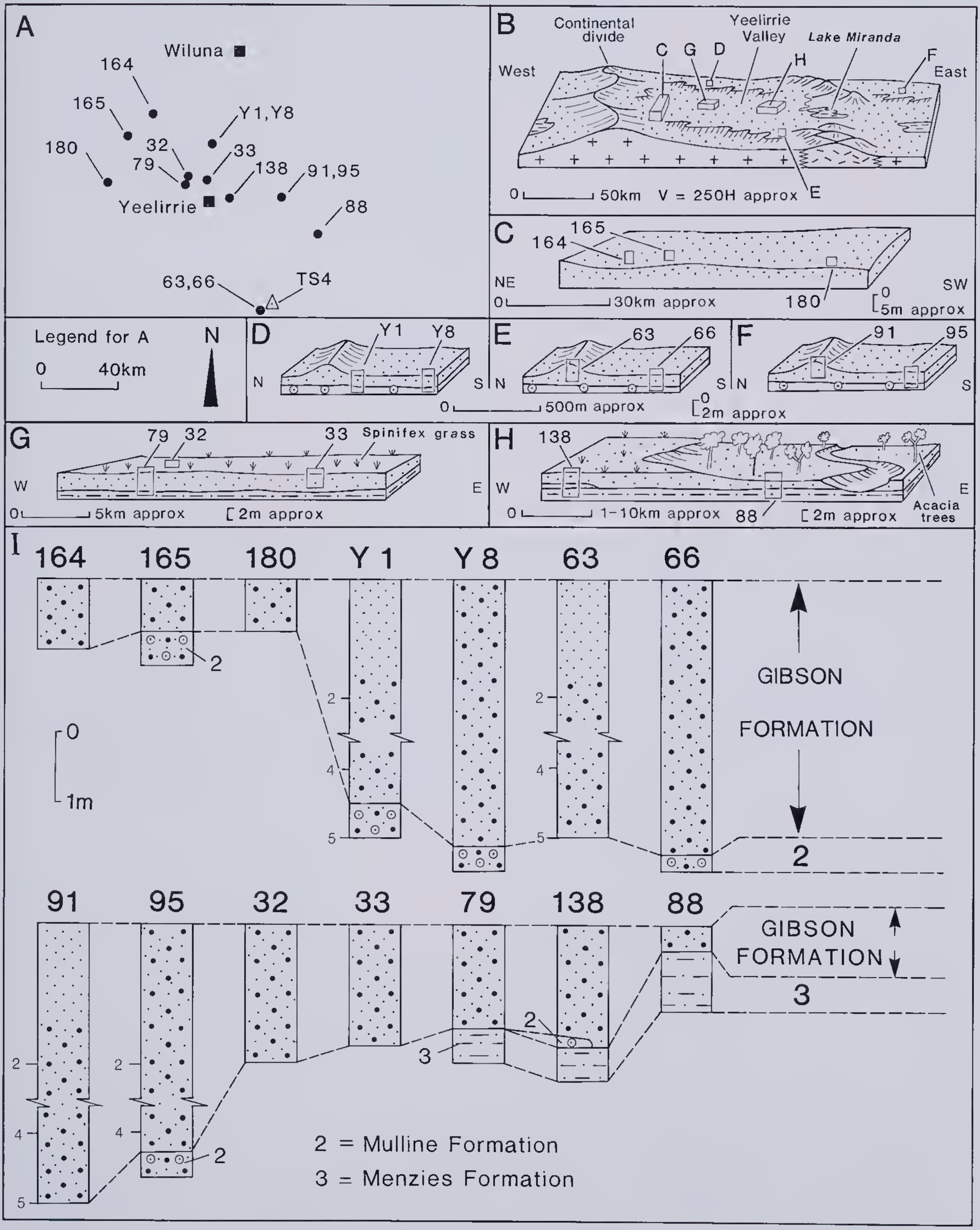

Figure 8.—Regional stratigraphy of the Gibson Formation in the Yeelirrie area. A. Location of sections. B, C, D, E, F, G, H. Geomorphic and stratigraphic settings of stratigraphic sections. I. Stratigraphic sections.

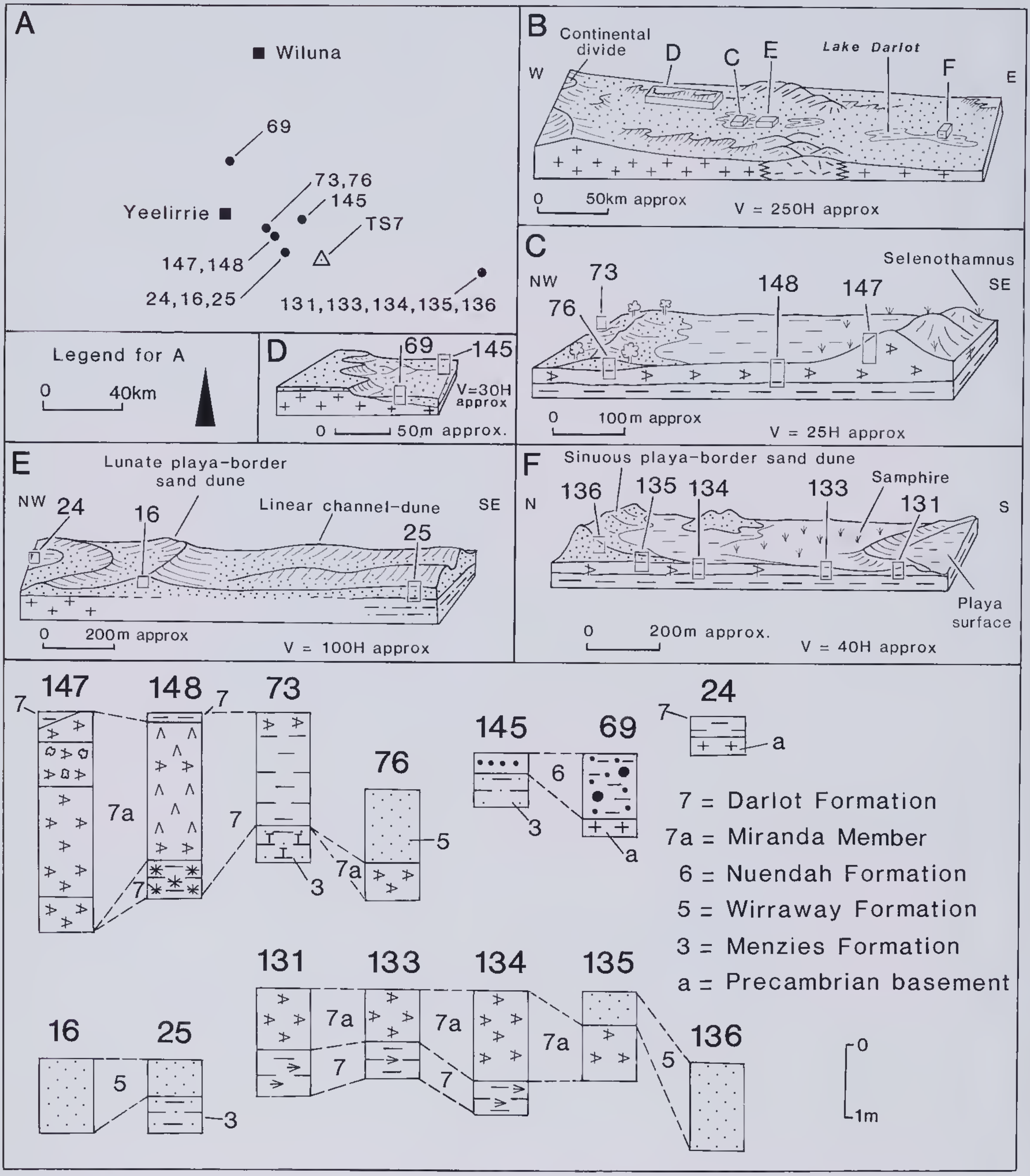

Figure 9.—Regional stratigraphy of the Wirraway, Nuendah and Darlot Formations in the Yeelirrie area. A. Location of stratigraphic sections. B,C,D,E,F. Geomorphic and stratigraphic setitngs of stratigraphic sections. G. Stratigraphic sections.

optimally developed kaolin spherites whereas the Wirraway Formation typically has no kaolin spherites or very few iron-rich kaolin spherites and fragments of kaolin spherites.

The surface of the unit designated Wirraway Formation has been mapped previously in the Yeelirrie area as: (1) Bullimore and Albany landform-regolith systems and described as aeolian and fluviatile deep sands, grits and clays and deep fluviatile and aeolian deposits respectively by Churchward (1977); (2) Quaternary aeolian deposits (Qrs), white to yellow quartz sand, red brown silty sand, in sheets and dunes marginal to salt lakes and calcrete by

Table 7

General outline of grain size properties for facies of the Wirraway Formation. Grain size terminology after Folk (1974).

Facies	General outline of grain size properties
Extra-playa	
Channel-border dunes	Poorly unimodal to unimodal, strongly fine to fine-skewed, moderately to poorly sorted, fine sand with 4 to 26% fines (<0.09 mm)
Playa-border	
Sheets	Poorly unimodal to unimodal, near-symmetrical, moderately to poorly sorted, medium to fine sand with 8 to 14% fines (<0.09 mm)
Sinuous dunes	Poorly unimodal to unimodal, strongly fine to fine-skewed, moderately well to moderately sorted, medium to fine sand with 3 to 7% fines (<0.09 mm)
Lunate dunes	Poorly unimodal to unimodal, strongly fine to coarse-skewed, moderately well to poorly sorted, very coarse to fine sand with 4 to 20% fines (<0.09 mm)
Intra-playa	
Sheets	Poorly unimodal to unimodal, near-symmetrical, moderately sorted fine sand with up to 20% fines (<0.09 mm)
Dunes (modern)	Poorly unimodal to unimodal, strongly fine-skewed to symmetrical, moderately well to moderately sorted, medium to fine sand with 0.5 to 3% fines (<0.09 mm)

Bunting and Williams (1979); and (3) channel-border and playa-border aeolian clayey sand and sand (Glassford 1980).

Nuendah Formation

The Nuendah Formation is the name proposed for pale brown gravels, sands and clayey sands which occur along Precambrian basement ridge-footslopes, breakaway-fronts and dendritic tributary drainage tracts of major valley sides. The formation typically overlies Precambrian basement and the Menzies and Gibson Formations (Tables 1,8).

Derivation of name. Named after Nuendah, lat. 27°2'S. long. 120°21'E, Sir Samuel 1:250 000 sheet.

Type section. The designated type section is the south bank of the Jones Creek, 47.5 km SE of Yeelirrie homestead where a telegraph line crosses Jones Creek, lat. 27°29'S, long. 120°31'E, Sir Samuel 1:250 000 sheet (Table 8; Figs 4,TS6:6A,E,F). One supplementary reference section west of the Yeelirrie to Community Bore road, lat. 27°4'S, long. 120°8'E, Sir Samuel 1:250 000 sheet (Fig. 9, site 169) is designated to include a facies not evident in the type section. This supplementary section exposes light brown clayey sand 50 m from the base of the breakaways.

Table 8

General description of lithology, Nuendah Formation type section.

Depth (m)	Description	Rock unit
0-0.9	Sand; light brown, faintly stratified, framework supported, poorly unimodal, near symmetrical, poorly sorted, medium, quartz sand.	
0.9-1.75	Sand; light brown, faintly stratified, framework supported, poorly unimodal, fine skewed, coarse, quartz sand.	
1.75-2.75	Gravelly sand; light brown, faintly stratified, framework supported, poorly unimodal, strongly fine skewed, poorly sorted, coarse, quartz sand	Nuendah Formation
2.75-5.0	Sandy gravel; light brown, massive, poorly unimodal, near symmetrical, poorly sorted, granule quartz and lithoclast gravel.	
5.0-6.0+	Sandy claystone; reddish brown.	Menzies Formation

Distribution. The Nuendah Formation occurs on valley sides of the Yeelirrie valley. At this scale it occurs as narrow belts along the base of NW to SE and west to east trending breakaways, along the footslopes of NNW trending Precambrian basement ridges and in dendritic tracts along tributary drainage lines which extend from breakaway-fronts and ridge-footslopes to major valley bottoms (Fig. 10).

Surface features. Breakaway-front facies have relict depositional surfaces to locally modern depositional and erosinal surfaces. Ridge-footslope facies have relict and erosional surfaces. Dendritic tributary facies have modern depositional surfaces.

Geometry and dimensions. The Nuendah Formation has a variable geometry. It occurs at the base of breakaways as a thin ribbon-like fringe or incipient bajada up to a few metres thick, a few hundred metres wide and up to many kilmetres long. It occurs along the footslopes of Precambrian basement ridges as gullied fans and also extends as thin, braided to discontinuous veneers, a few millimetres to a few decimetres thick, along intermittent tributary drainage lines (Figs 6A,E,F:9).

Lithic characteristics. The Nuendah Formation contains the following facies: (1) coarse to fine sand; (2) gravel to fine sand; (3) medium to fine clayey sand, and (4) gravel to coarse sand.

The coarse to fine sand facies occurs in ridge-footslope overbank locations. Along the footslopes drained by the Jones Creek it consists of two major beds. A basal upward fining graded bed of light brown, moderate to poorly sorted coarse quartz with minor amounts of basement lithoclast granule gravel to coarse quartz sand, and an upper, upward fining graded bed of light brown, coarse skewed, poorly sorted, medium to fine quartz sand.

The gravel to fine sand facies occurs in channels draining ridges and dendritic tributary channels which drain breakaway-fronts and major valley sides. It consists of basement lithoclast and quartz gravels and sands. The haematite and goethite pigmented kaolin grain-coatings are generally less on overbank and channel sands when compared with similar coatings on Gibson Formation sands.

The medium to fine clayey sand facies occurs along breakaway-fronts as bajada and pediment deposits. This facies is massive, light brown to light reddish brown, poorly sorted, medium to fine, clayey sand. It is composed of quartz and kaolin with minor kaolin spherites.

The gravel to coarse sand facies occurs at the base of breakaways as a scattered pebble to granule float or talus over the medium to fine clayey sand facies and is derived from the breakaways. Further from the breakaways the clayey sand is covered by a patchy, millimetre-thin veneer of white, moderate to poorly sorted, very coarse to coarse quartz sand.

Fossils. No fossils have been found in the formation.

Stratigraphic relationships. Along the front of breakaways the Nuendah Formation overlies granitic rock and interfingers downslope with the Gibson Formation. Along the footslope of basement ridges it overlies the Menzies Formation. In upper tracts of tributary drainage lines it overlies the Gibson Formation. In lower tracts of tributaries it overlies the Menzies Formation and interfingers with the Wirraway Formation (Figs 4,TS6; 6A,E,F;9).

The upper boundary of the Nuendah Formation is typically the modern land surface. The surface alternates intermittently from one dominated by deposition to one dominated by erosion. Thus the upper bounding surface is commonly devoid of vegetation.

The facies of the Nuendah Formation are laterally equivalent because firstly they are still being formed at the present day land surface; secondly they are laterally intergradational in pit and outcrop profiles; and thirdly they all tend predominantly to overlie the Menzies and Gibson Formations.

Discussion. Along breakaway-fronts the Nuendah Formation is derived mainly from Gibson and Westonia Formations at the top of breakaways, and from deeply weathered granitic rocks which comprise much of the lower part of breakaways. Near basement ridge-footslopes it is derived from basement rocks and the Wiluna Formation. Along the lower tracts of tributary drainage lines it is derived mainly from the Gibson and Wiluna Formations.

The unit designated Nuendah Formation has been mapped in the Yeelirrie area as: Nuendah, Marloo, Keith and Yakabindie landform—regolith systems by Churchward (1977); Quaternary alluvium (Qpv), and colluvium (Qqc, Qpm) by Bunting & Williams (1979); and as footslope channel, overbank and fan alluvial deposits (Glassford 1980).

Darlot Formation

The Darlot Formation is the name proposed for a unit of pan silt-clay, playa ("salt lake") gypseous muds and playa border gypsum deposits which overlie Precambrian basement the Menzies and Gibson Formations and interfingers with the Wirraway and Nuendah Formations (Tables 1,9). The Darlot Formation contains a lithologically distinct and mappable unit and it is proposed to name this unit the Miranda Member (see later).

Derivation of name. Named after Lake Darlot, lat. 27° 45′S, long. 121°E to lat. 27°45′S, long. 121°30′E, Sir Samuel 1:250 000 sheet.

Type Section. The designated type section is a NE facing escarpment in an island within Lake Miranda, lat. 27° 40′S, long. 120°33′E, Sir Samuel 1:250 000 sheet (Table 9; Figs 4,TS7;6A,E,G).

Distribution. The Darlot Formation occurs intermittently along the axis of the Yeelirrie valley as a discontinuous series of foci or sumps for surface and subsurface drainage. It extends down valley as a chain of pan, playa and playa-border deposits (Figs 4,6,9,10).

Surface features. All lithofacies have ancient buried and relict surfaces in addition to modern depositional surfaces. Modern mud flats and sand-dune surfaces have no vegetation. Relict gypsum surfaces have a very sparse to negligible vegetation typically *Selenothamnus* sp., *Arthrocnemum* sp. and related genera whilst relict sand-dune surfaces have a variety of grasses, scattered shrubs and trees (Beard 1976).

Table 9

General description of lithology, Darlot Formation type section.

Depth (m)	Description	Rock unit
0-0.01	Mudstone; white, massive, hard, silt and clay sized gypsum.	Miranda Member of the Darlot Formation
0.01-1.25	Sandy silt-clay: white, soft, powdery, massive, silt and clay gypsum with minor unimodal, fine skewed, well sorted, very fine, quartz sand.	
1.25-1.26	Crystalline gypsum; white to light brown, hard, massive.	
1.26-2.0	Sandy gypsum; white to light brown, poorly consolidated.	
2.0-2.01	Crystalline gypsum, white to light brown, hard massive.	
2.01-3.1	Sandy gypsum; white to light brown, poorly consolidated.	
3.1-3.45	Sandy gypsum; white to light brown, cross-stratified quartz and gypsum sand.	
3.45-3.46	Crystalline gypsum; light brown, hard.	
3.46-4.25	Crystalline gypsum; white to greenish grey, hypidiomorphic gypsum.	
4.25-5.0	Crystalline gypsum; pink to red, hypidiomorphic gypsum.	
5.0-5.6	Mud; red masive gypseous kaolin mud with gypsum rosettes.	Darlot Formation
5.6-7.0	Concealed section.	
7.0-8.0+	Gypseous mud; reddish brown gypseous kaolin mud.	

Geometry and dimensions. The formation varies markedly in geometry and thickness. It occurs as discrete tabular to lenticular sheets and ribbons, discrete circular to elongate to irregular basins, or as irregular to sinuous to lunate hills. It ranges from less than 1 m thick (e.g. small clay pans) to 7 m thick at the type section and to perhaps tens of metres thick (e.g. large playas).

Lithic characteristics. The Darlot Formation has the following facies: (a) gypseous mud; (b) white quartz sand; and (c) a variety of gypsum deposits, which will be described under the Miranda Member (Figs 4,TS7;9).

Gypseous mud facies occurs as modern playa mud flats at the surface. It ranges from red to reddish brown to locally grey, is massive to flat bedded and laminated and ranges from gypseous kaolin mud to kaolinitic gypsum mud, usually with up to 5% very fine sand to silt sized quartz. Near the water table this facies generally consists of large crystals of authigenic euhedral gypsum, often in rosettes, with moderate to minor kaolin mud matrix. Relict equivalents of this facies may be either buried with little alteration, or truncated with the upper gypseous kaolin mud removed to leave underlying kaolinitic crystalline gypsum. Playa deposits are commonly buried under sheets and dunes of gypsum silt-clay and dunes of gypseous quartz sand and quartzose-gypsum sand.

White quartz sand facies occur as shoestring beach deposits around the margins of playa mud flats. It varies from a few millmetres to several decimetres thick and from a few centimetres to a few metres wide. The sand commonly contains loose plant debris, algal filaments in patchy mats and sometimes bivalve and *Coxiella* shells.

Fossils. A few *Coxiella* shells are locally buried in playa-border dunes.

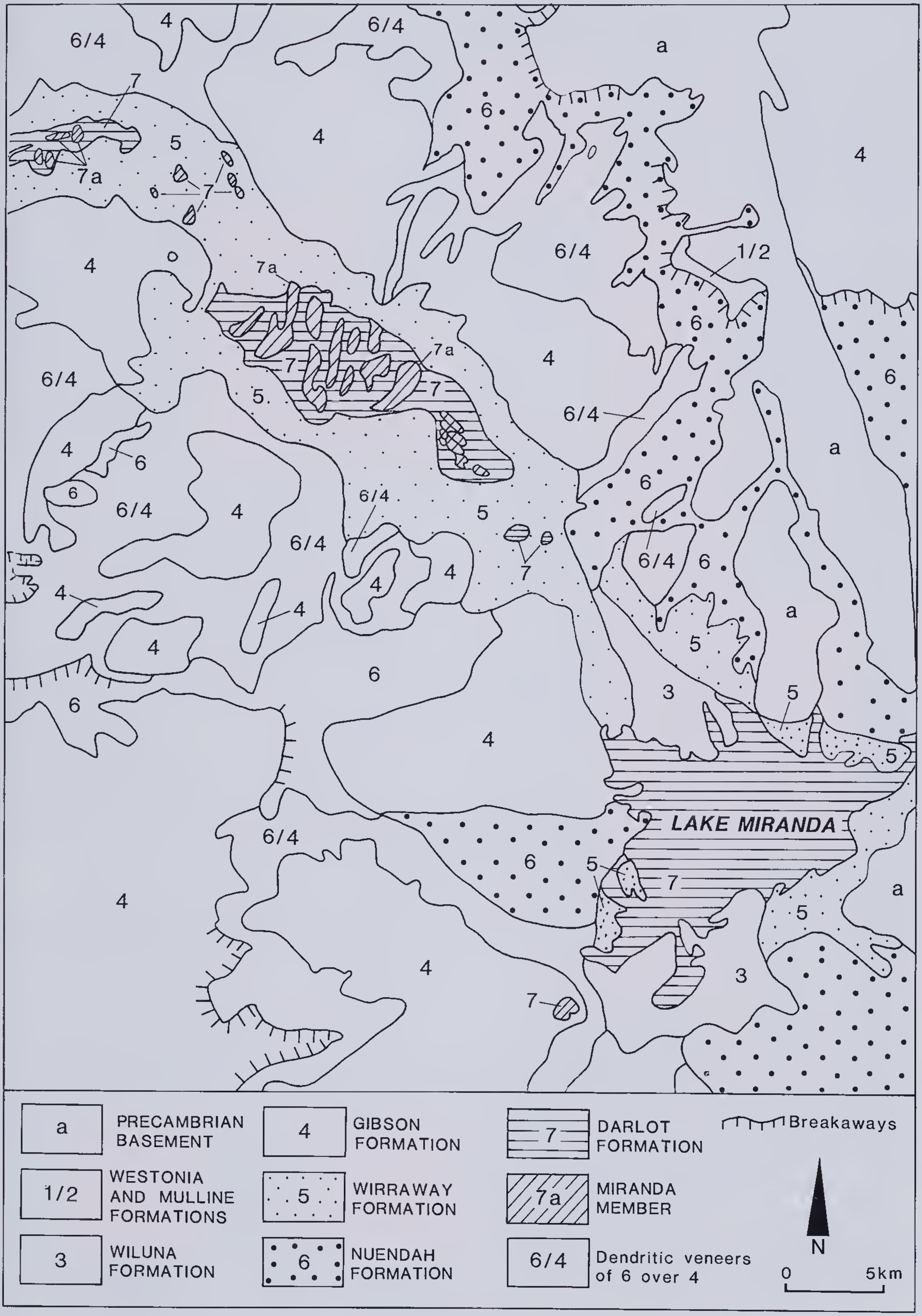

Figure 10.—Map showing distribution of formations in the lower central Yeelirrie valley. See Fig. 1 for location.

Stratigraphic relationships. The Darlot Formation occurs in the lowest part of the landsurface and therefore its lower boundary is nearly always concealed. However costean and pit excavations indicate that occasionally, clay pans of the Darlot Formation develop within, and therefore overlie the Gibson and Wirraway Formations, in addition to the Menzies Formation and Precambrian basement, with a sharp straight contact (Fig. 9).

Miranda Member of Darlot Formation. This unit is named after Lake Miranda, lat. 27°40'S, long. 120°33'E, Sir Samuel 1:250 000 sheet.

The Miranda Member consists of sheets and hills of gypsum, over 5 m thick at the type section (Fig. 4,TS7). The unit interfingers with relict play muds and also channel-border dunes of the Wirraway Formation. At the type section it consists of three main facies: (a) gypsum sand and sandstone; (b) crystalline gypsum; and (c) gypsum silt-clay.

Gypsum sand and sandstone facies occurs as sheets and dunes overlying and marginal to playa flats. It is loose to weakly lithified, crudely stratified and consists of brownish to off-white gypsum, and minor to moderate amounts of quartz. The quartz is essentially clean, that is, it is white with no goethite or haematite pigmented kaolin clay coatings.

Crystalline gypsum facies consists of tightly-fitted crystals of idiotopic gypsum. The primary gypsum has probably been modified by ground-water precipitation of secondary gypsum.

Gypsum silt-clay facies occurs as dunes and sheets marginal to modern playas or completely covering former playa mud flats. It is nearly everywhere massive, commonly white, and in places brownish white to grey. When dry the gypsum is a dusty powder. With increasing moisture content it grades to a soft plasticine-like consistency. This facies is commonly vegetated by *Arthrocnemum* and related samphire genera plus the peculiar candelabrum-shaped *Selenothamnus helmsii* (Beard 1976).

Discussion. The Darlot Formation has a varied provenance. Sedimentary materials have been derived from both clastic and soluble components of Precambrian basement rocks in addition to all the previously described formations. Furthermore, the playa facies and playa-border facies have both acted intermittently as source materials for each other. However playa facies appear to be the dominant source for playa margin deposits, whereas the latter facies appear to be a minor source for playa facies.

Kaolin spherites become pitted and fragmented and coatings of clay on quartz grains are removed when these grains are immersed in water. Consequently the presence of these grains in minor trace amounts in concert with their relative degree of preservation can be used to distinguish between sands of the Nuendah or Darlot Formations which have themselves been derived from the Gibson and Menzies Formations.

The surface of the unit designated Darlot Formation has been mapped by previous authors as: Miranda landform—regolith system and described as deep fluviatile, lacustrine and aeolian deposits of saline clays and gypseous and calcareous earths by Churchward (1977); Quaternary lacustrine (Qra), lacustrine and alluvial (Qrm), aeolian (Qpk) deposits by Bunting & Williams (1979); and playa and associated sub-aqueous and aeolian deposits (Glassford 1980).

Table 10

Summary of main lithology for Cainozoic lithostratigraphic units of the Yeelirrie area.[1]

Name	Main lithology
7. Darlot Formation	Gypseous sands and muds
6. Nuendah Formation	Lithoclast and quartz gravel and sand and light brown clayey quartz sand
5. Wirraway Formation	Red quartz sand
4. Gibson Formation	Red to yellow quartz and kaolin spherite sand
3. Menzies Formation	Red sandy clay/claystone
2. Mulline Formation	Reddish to yellowish brown, sandy lateritic to bauxitic pisolitic duricrust.
1. Westonia Formation	Grey sandy claystone (in places silicified)

[1] Units are listed from youngest at top to oldest at bottom. It should be noted that the Darlot, Nuendah and Wirraway Formations interfinger with each other and to a small extent with the Gibson Formation. Also the Gibson Formation typically, unconformably overlies the Mulline and Menzies Formations and the Mulline and Menzies Formations typically, unconformably overlay the Westonia Formation which in turn typically, unconformably overlies saprolite which has developed in Precambrian basement. The Mulline Formation includes primary and secondary (reworked) duricrust materials and in the Yeelirrie area the Westonia Formation has been silicified.

Discussion

The stratigraphic details presented herein show that the Cainozoic cover of the Yeelirrie area consists of seven main lithologic units (Table 10): (1) Westonia Formation (mainly grey sandy claystone with silicification); (2) Mulline Formation (mainly reddish to yellowish brown sandy laterite); (3) Menzies Formation (mainly red sandy clay and sandy claystone); (4) Gibson Formation (mainly reddish yellow siliciclastic sand, that is composed of quartz and kaolin spherites); (5) Wirraway Formation (mainly red quartz sand); (6) Nuendah Formation (mainly gravel to gravelly sand to light brown clayey sand); and (7) Darlot Formation (mainly gypseous sands and muds). In terms of landsurface occurrence, geomorphic expression, surface features, geometry, structure, fabric, texture (e.g. modality, modal size, mean size, size sorting, size skewness and fines), composition (e.g. mineralogy of grains, grain coatings), stratigraphic relationships and diagenetic/pedogenetic overprints (Table 1) these formations are distinctive and readily recognizable rock units.

These units are sufficiently distinctive and consistently distinguishable in the attributes outlined above to be mapped as separate discrete entities (Figs. 5,10), thereby satisfying the requirements for formation status (Hedberg 1976, North American Commission on Stratigraphic Nomenclature 1983, Staines 1985).

The proposed lithostratigraphic framework provides a relatively objective basis for more detailed future work into the nature and origin of the cover in the Yeelirrie area and also throughout other parts of the Yilgarn Block (Fig. 3). This is because the recognition and description of lithostratigraphic units is based on observable non-genetic physical features (Hedberg 1976, p.31). In contrast to most previous work, *a priori* assumptions of genesis or developmental history, essentially play no part in the framework presented here. Consequently interpretations of origin for the units of this study have not been made. Such interpretations are considered premature at present because of the paucity of any integrated and thorough documentation of the major genetically critical attibutes (e.g. stratigraphy, geometry, structure, texture and composition) of these or any other Cainozoic deposits of the Yilgarn Block. Interpretations

of origin will be presented at a later date after all the genetically critical attributes have been described for the respective units.

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The Bridport Calcilutite

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Abstract

The term Bridport Calcilutite is proposed for the sequence of Holocene sediments consisting predominantly of homogeneous to bioturbated carbonate mud and shelly carbonate mud. These sediments occur in the contemporary marine environment and in the subsurface of the coastal zone of the Swan Coastal Plain. The sediments have formed as submarine basin deposits in deep water quiescent environments in proximity to seagrass banks.

Introduction

The Holocene coastal zone of the Perth Basin presents a variable suite of facies and sedimentary deposition systems that include aeolian sands, beach deposits, seagrass bank accumulations, deltas, estuarine accumulations and sediments of the nearshore shelf and coastal rocky reefs. Generally each of these depositional systems are distinct in their mode of sedimentation, and they generate sediment accumulations which are of sufficient size and extent to be recognised as formations. Indeed, the various major types of Holocene coastal sediment accumulations already have been formally recognised as formations; e.g. the Safety Bay Sand, the Becher Sand, the Leschenault Formation (Passmore 1970; Playford *et al.* 1976; Semeniuk 1983; Semeniuk and Searle 1985).

Additional stratigraphic studies along the coastal and marine environments of southwestern Australia have further delineated a suite of coastal sediments, that have distinct lithologic characteristics, which should be formally assigned formation status. It is the purpose of this paper therefore to establish a new formation, the Bridport Calcilutite, for a sequence of Holocene deep water marine carbonate muds and shelly muds in the coastal region of southwestern Australia.

Data for this paper were obtained from coastal plain and submarine environments by reverse air core drilling, air-lift drilling and intact cores. Locations of drill sites that intersected the Bridport Calcilutite are shown in Fig. 1.

Regional Setting

The study area is set along the coastal zone and nearshore marine environment of the Rottnest Shelf of southwestern Australia (Carrigy and Fairbridge 1954). This coastal system is comprised of Holocene sediments as well as erosional surfaces cut into Pleistocene materials, and encompasses the seaward extremity of the Swan Coastal Plain, a Quaternary sedimentary system of the Phanerozoic Perth Basin (Playford *et al.* 1976).

The most important sites of sediment accumulation along the southwestern coast occur in the Cape Bouvard-Trigg Island sector of Searle and Semeniuk (1985). This sector is characterised by shore-parallel limestone ridges, in various stages of erosional degradation, with intervening deeper water marine depressions (Searle 1984). Holocene sedimentation, mainly restricted to loci termed accretionary cells (Searle 1984), has formed platforms, east-west oriented banks and subaerial promontories that span and segment the most eastern marine depression (the Cockburn-Warnbro Depression) to form a series of basins (Searle and Semeniuk 1985).

The shallow water submarine banks and platforms are seagrass-covered and are sites where seagrass-derived sediments (bioburbated to shelly quartzo-skeletal sand and muddy sand) accumulate to form deposits referred to as Becher Sand (Semeniuk and Searle 1985). In the deeper water marine basins, where depths are >18 m and sediment floors are extensive, flat and featureless, there is accumulation of carbonate mud and shelly mud. These carbonate mud deposits have been described sedimentologically by Carrigy (1956) and Searle (1984), and are the lithotope of the Bridport Calcilutite, the subject matter of this paper.

Definition of the Bridport Calcilutite

The Bridport Calcilutite is the formation name proposed for the sequence of grey, structureless to bioturbated, calcareous (carbonate) mud with lesser shelly carbonate mud. The formation forms the floors and underlies modern (contemporary) deep water marine basins, and also occurs in the subsurface, typically underlying the Becher Sand. The formation name is derived from Bridport Point, in the southern part of Warnbro

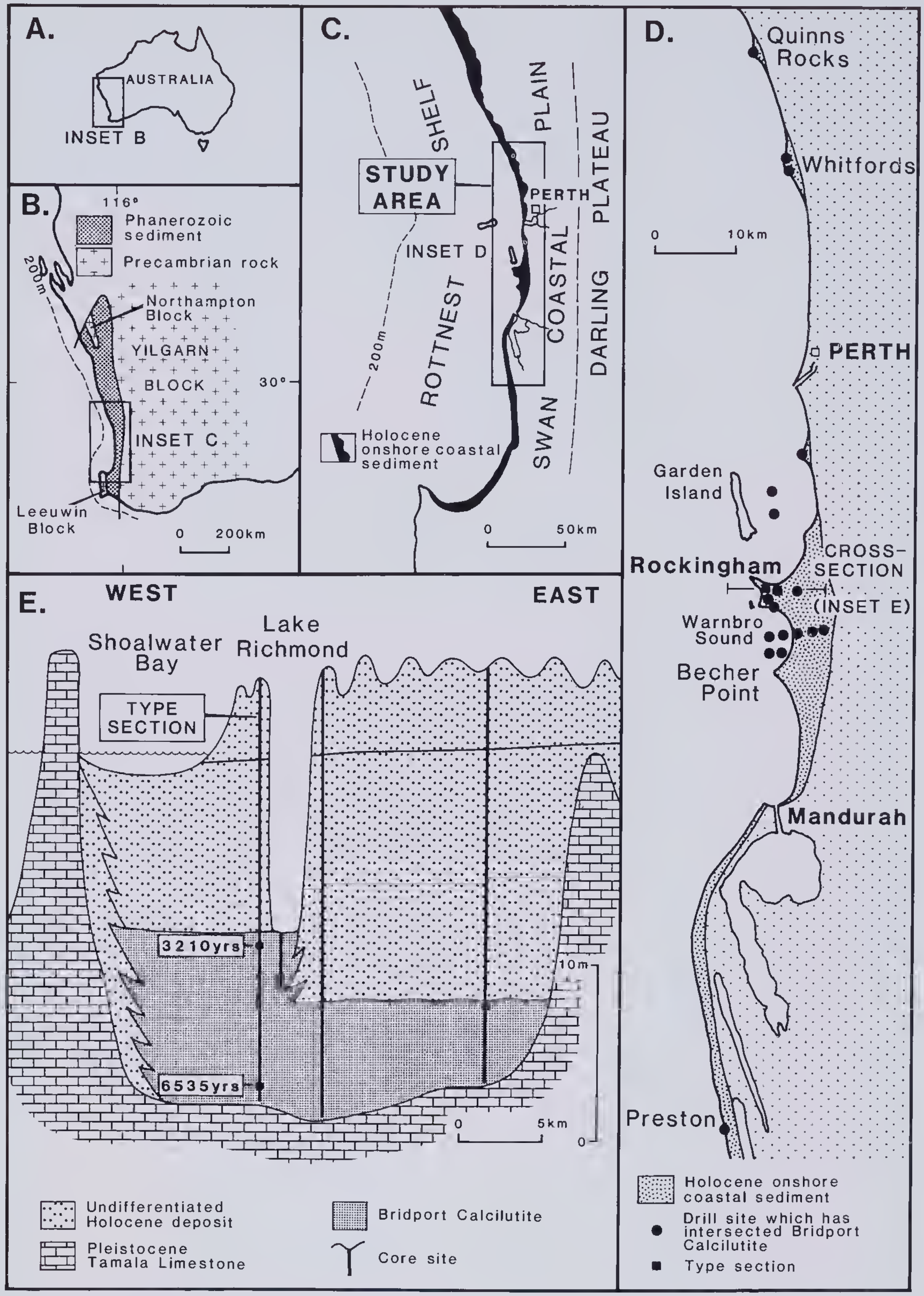

Figure 1.—A and B. Locality diagram and setting within the Perth Basin.
C. Location of study area.
D. Location of drill sites where Bridport Calcilutite has been intersected.
E. Stratigraphic cross-section showing extent, thickness and east-west geometry of the Bridport Calcilutite along a transect situated near Rockingham. Radiocarbon ages within the Bridport Calcilutite at the type section are samples GX12904 and GX12903; both have been corrected for C13.

Sound, which is a basin where the Bridport Calcilutite is accumulating. The lithologic term calcilutite is aptly applied in that the proposed formation consists of calcareous lutaceous sediment (Bates and Jackson 1980).

Type Section: The core site on the west shore of Lake Richmond, in the Rockingham area, is designated as the type section (Fig. 1). Material from the core has been lodged with the Geological Survey of Western Australia. The sequence within the type section is described as follows:

Top (Becher Sand): fine to very coarse grey carbonate/quartz sand, locally shelly ...... 10.5 m

Bridport Calcilutite: homogeneous, grey/fawn, carbonate mud with seagrass fibre .... 6.0 m

homogeneous, grey, carbonate mud with shell .... 0.5 m

homogeneous, light grey, carbonate mud ... 3.0 m

Base (Tamala Limestone): calcreted aeolianite limestone .... 2.0 m

Distribution: The Bridport Calcilutite has been intersected in numerous cores and its distribution, both contemporary and subsurface, is widespread (Fig. 1).

Geometry and Thickness: The formation is up to 10 m thick under the coastal plain in the Rockingham area. Elsewhere the formation is generally 2-6 m thick. In localities where it is contemporary, the unit forms a sheet-like to lens-like body on basin floors. In the subsurface where it has been buried by the Becher Sand, as in the Becher Point-Rockingham Plain area, it forms a seaward thickening wedge body, or a thick prism.

Lithology: The dominant sediment in the formation is grey, structureless to bioturbated, calcium carbonate mud composed of clay-sized and silt-sized carbonate material. Locally there are layers with marine shells, layers of laminated calcareous mud, and horizons of seagrass fibre and seagrass peat.

Stratigraphic relationships: The formation overlies the following units:

1. Tamala Limestone (sharp unconformable contact).
2. Cooloongup Sand (bioturbated to gradational unconformable contact),
3. Mud of the Leschenault Formation (bioturbated, gradational, conformable contact).

The formation may be overlain by the bioturbated, grey sediments of the Becher Sand, and the contact is conformable and mostly sharp.

Age and fossils: The Bridport Calcilutite is wholly Holocene. Radiocarbon ages from shells in the unit are less than 7 000 C14 yrs BP (Fig. 1). The Bridport Calcilutite is locally shelly and mollusc shells predominate. Molluscs include *Bittium granarium* and *Chlamys* sp. with less common *Clanculus ?plebejus*, *Cantharidus lepidus*, *Cantharidus irisodontes*, *Ethminolia ?vitiliginea*, *Diala* sp, *Nassarius pauperatus*, and *Brachidontes ustulatus*.

Discussion

The sediments referred here to the Bridport Calcilutite originally were considered part of the basal portion of the Becher Sand (see "unit of fawn coloured mud with seagrass fibre", Table 2 of Semeniuk and Searle 1985; "marine mud unit" in figure 2 of Semeniuk and Searle 1985; and "mud" in Figure 3 of Semeniuk and Searle 1986). However, the extensive drilling in the Rockingham-Becher Plain area has shown that the distinctive carbonate mud unit underlying the Becher Sand is up to 6 m thick, and that it is substantial enough in thickness and extent to be recognised as a separate formation. Drilling elsewhere, such as at Preston and Whitfords-Quinns Rock area, also has shown that the formation is not restricted just to the Cape Bouvard-Trigg I. coastal sector.

The occurrence of the unit has palaeo-enviromental implications. In the modern environment the formation is accumulating in quiescient, protected, deep water marine basins such as Warnbro Sound and Cockburn Sound. The mud is derived from adjoining seagrass bank environments where wave agitation and reworking entrains fine carbonate sediment into the water column. The suspended mud finds its way into the basins and settles out as a suspension deposit. Periodically, the substrates of the basin are inhabited by a mollusc fauna which contribute their remains to the sediment to form shell layers. The Bridport Calcilutite thus represents deposits of quiescent deep water marine basins that adjoin, or are protected by, seagrass bank environments.

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Book Jacobs M R 1955 Growth Habits of the Eucalypts. For Timb Bur, Canberra.

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